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THE APPLICATION OF REMOTE SENSING TO THE DEVELOPMENT

AND FORMULATION OF HYDROLOGIC PLANNING MODELS

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I. INTRODUCTION

The launch of LANDSAT has for the first time provided the water re-
source manager and practical hydrologist with broad prospects for effi-
cient acquisition of essentially real-time data. These are usable for
hydrologic land use assessment, surface water inventory, and for the ex-
traction of information pertinent to soil properties. This information
has value not only by and in itself, but also to construct the water-
shed transfer function for hydrologic planning models aimed at estima-
ting peak outflow from rainfall inputs.

The reduction of satellite data to practical, operational informa-
tion requires a clear, easily applicable methodology for converting
these data into quantitative hydrologic parameters.

The fundamental objective of this effort is the development of
such a methodology and its transfer to hydrologic users. It was rea-
lized that such technology transfer could be made far more effective
by the parallel development and eventual demonstration of the results
of a model, specifically structured to take full advantage of the ca-
pability of LANDSAT - for example, its frequent recurrence and conse-
quent ability to determine seasonal variations in the watershed's con-
ditions. The category of planning models was chosen for development
and demonstration because of its great practical importance in the de-
sign of waterworks, because of the wide diffusion of such models down
to capillary levels within the hierarchy of water resources users,
and because their implementation is relatively simpler than
management models, thus making optimum use of the resources available
for this effort.

Consequently, the effort was structured along two major routes: the development of a hydrologic planning model specifically based upon remotely sensed inputs, including its test and verification from existing records; and the application of LANDSAT data to supplying the model's quantitative parameters and coefficients. Included was the investigation of the use of LANDSAT data as information inputs to all categories of hydrologic models requiring quantitative surface parameters for their effective functioning.

The effort thus far has consisted of three phases. The first focused on the definition of the "drivers" - those hydrologic processes to which peak runoff is most sensitive - and upon the synthesis of a simple yet effective model for the estimation of long-recurrence outflows. The results of the first phase effort were presented in the Final Report, "The Application of Remote Sensing to the Development and Formulation of Hydrologic Planning Models," dated January, 1975. The second phase extended this work to include the development of a routing model for use in sensitivity analyses, and a quantitative investigation of the accuracy and completeness of the hydrologic information which can be extracted from remotely-sensed imagery.

These findings were reported in the January, 1976, final report. The current phase has concentrated on validation of the model and upon the synthesis of a simple methodology for performing hydrologic analyses from LANDSAT imagery.

II. SUMMARY OF RESULTS AND CONCLUSIONS

The objectives of the current effort have been to complete and test a hydrologic planning model making maximum use of remotely-sensed inputs; to document procedures for extraction of pertinent parameters from satellite data; and to expose the model and techniques to prospective users.

In the course of this investigation, several findings and conclusions have been reached and are described below:

The Importance of Surface Parameters to Hydrologic Models

The surface-related parameters used by existing hydrologic models (Manning's "n," S.C.S. Curve Number, etc.) can be derived from LANDSAT imagery to the required accuracy. The opportunity is available to take advantage of the radiometric and multi-temporal properties of the data to facilitate identification and classification. Moreover, potentials exist for remote monitoring of soil and soil moisture which would be of great value to hydrologists.

Planning Model Development

A simple model which is amenable to remote sensing inputs has been developed and tested; it exploits LANDSAT data for surface cover input and can accept soil moisture information as this becomes possible. The test was performed for the Bucklodge Branch, Maryland, watershed. Accuracy achieved to date appears commensurate with those of conventional models. The principal purpose envisioned for the model and benchmark test is to demonstrate to prospective users that satisfactory results can be achieved and to show how similar analysis procedures might be applied to their watershed with their models.

Synthesis of Analytic Procedures

Our experience has shown that a significant share of hydrologic modeling is being performed under the auspices of local governments. Consequently, two impediments to the use of satellite data arise. First, there is a lack of standard procedures for extraction of hydrologic data. Second, the expense involved with current computer/optical practices is a deterrent to use. This report proposes a procedure for simple visual analysis of LANDSAT images which is accurate enough for use in conjunction with hydrologic models. It has been determined further that these techniques extend beyond the field of hydrology and can have equal applicability to agriculture, land use, etc., analyses.

Contacts with Prospective Users

To date, contacts have been made with both foreign and domestic users. Due to the relatively new state of modeling overseas, the response has been greater there. One Italian region has embarked on the analysis of a major watershed, spawned in part by this investigation. Other regions have expressed interest. Domestic acceptance will be fostered by the demonstration of concise procedures and satisfactory results. Such a purpose is intended for this document.

III. REVIEW OF PREVIOUS PHASES

Of critical concern to water resources planners and engineers is
the ability to forecast peak flow events. The capacity to estimate the
magnitude and duration of large-recurrence outflows has a significant
impact upon the accuracy of sizing and designing waterworks, and thus on
their cost.

The tool available to the planner for these purposes is the hydro-
logic model. Although the inputs of different models vary, all require
significant quantities of physiographic and hydrologic information; these
data are typically expensive to obtain and are often only partially avail-
able. Remote sensing offers a new source of information which formerly
had to be acquired by less efficient means or ignored altogether.

The first phases of this effort conducted from February, 1974 to
December, 1975, addressed four pertinent topics:

1) Identification of the "drivers" of peak flow events, i.e.,
   the hydrologic phenomena (infiltration, antecedent soil
   moisture, etc.) to which the watershed's outflow is most
   sensitive.

2) The development of a model compatible to the maximum degree
   with remotely-sensed hydrologic inputs.

3) Preliminary verification of the model for actual watersheds.

4) Initial identification of the efficiency of remote sensing
   in determining the parameters of the model.

3.1 Investigation of Driver Phenomena

The purpose of this investigation was to achieve a valid statistical comparison of the rates and magnitudes of the hydrologic processes contributing to the runoff from long-recurrence events. This was accomplished over a significant sample of watersheds, with wide variation of climatology, terrain, and physiography. The comparison allowed the determination of which are important and which can be neglected without significant loss of accuracy.

Rain falling on a watershed is subject to several processes which abstract water and govern the flow. Those which produce the most significant changes to flow rates and volumes "drive" the basin outflow. Table 1 describes the hydrologic processes; Table 2 presents the "drivers" of each. It shows that several processes can be omitted in the formulation of a peak rate model because of their limited impact. For example, the rates corresponding to interflow, percolation, and evapotranspiration are very slow in comparison with other processes such as rainfall, infiltration and overland flow. Also, interception and depression storage become saturated early in large rainfall events and therefore are inconsequential to peak event modelling.

Therefore, except for very special circumstances, peak flow can be adequately modelled by considering only precipitation, infiltration and surface flow - both overland and in the channels. The means by which this can be accomplished will be discussed in Section V.

TABLE 1

SUMMARY DESCRIPTIONS OF HYDROLOGIC PROCESSES

HYDROLOGIC PROCESS	DESCRIPTION
Interception	Moisture caught and stored on plant leaves and stems or other impermeable objects; eventually evaporated back into the atmosphere.
Infiltration	Downward movement of water from the surface into the soil.
A) Interflow	Lateral subsurface water movement toward stream channels.
B) Percolation	Downward movement of water through soil to groundwater (area where pores of soil or rock are filled with water).
C) Base Runoff	Water from interflow and percolation which moves underground to the channel.
Evapotranspiration	
A) Evaporation	Upward movement of water in gaseous state from the surface.
B) Transpiration	Movement of water through plants to the atmosphere.
Precipitation Excess	
A) Depression Storage	Retention of excess rainfall in surface depressions.
B) Surface Flow	Uninfiltrated water which flows over land surface to stream channels.
C) Channel Flow	Flow of water in natural channels.
Total Runoff	Sum of runoff from underground processes (base runoff) and overland flow (direct runoff).

TABLE 2

POTENTIALLY IMPORTANT DRIVERS AS RELATED TO HYDROLOGIC PROCESSES

HYDROLOGIC PROCESS	PRINCIPAL DRIVERS	SECONDARY DRIVERS
Overland Flow	Slope Roughness of Soil & Cover Drainage Density & Pattern	— —
Infiltration	Soil Permeability Antecedent Soil Moisture Soil Moisture Capacity	Vegetative Cover Slope Water Turbidity Temperature
A) Interflow	Soil Permeability Subsurface Moisture Gradient Flow Length, Slope	— —
B) Percolation	Soil Permeability Subsurface Moisture Gradient Soil Depth	— —
Evapotranspiration A) Evaporation	Temperature Antecedent Soil Moisture Soil Permeability	Water Turbidity Wind
B) Transpiration	Temperature Solar Radiation Vegetative Cover Antecedent Soil Moisture	Wind
Depression Storage & Detention	Depression Density Cover Retention	Slope
Interception	Duration of Rainfall Intensity of Rainfall Cover Composition, Age, Density	Evaporation Rate

3.2 Development and Validation of Remote Sensing Model

The following criteria were followed in the structuring of a peak-rate model:

1) The model would be modular, to allow the user flexibility of application,

2) The model would maximize potential input from remote sensing.

During the first phase a model of the Rational Formula type was developed. It is of the form:

$$Q = 2Ll \ \xi \left[\frac{\phi \ (l) \ (n)^{.6}}{\xi^{.4} \ s^{.3} \ (3600)} \right]^{\frac{1}{0.4 - \frac{1}{\alpha_3}}} \tag{1}$$

where:

Q = maximum outflow rate, $m^3/sec/km^2$

L = channel length, m

l = length of average strip, m

n = average Manning's "n"

ϕ = routing factor

$\xi = K \ \alpha_1 \ T^{\alpha_2}$

K = infiltration and spatial correction factor

T = rain recurrence interval, years

s = average slope, m/m

$\alpha_1, \ \alpha_2, \ \alpha_3$ = constants, function of location

The output of this model is the expected peak discharge rate for a watershed for a rainfall of T years recurrence interval (A complete derivation is contained in the January, 1975 report). This model was

verified against records of 31 experimental watersheds of the Agri-
cultural Research Service. The results showed this model to equal
or better the performance of other formulations of the Rational type.

In the second phase, the two criteria of modularity and remote
sensing input maximization were applied to the development of a more
comprehensive model capable of routing water overland and through the
channels. This model as envisioned would have maximal utility for un-
gaged, predominantly rural watersheds, i.e., those where remote sensing
could play a significant role. Completion and verification of the model
occurred during the current effort and will be reported later in this
document.

3.3 Identification of the Efficiency of Remote Sensing in Determining Parameters of Hydrologic Models

This task was comprised of hydrologic land use analysis of water-
sheds located as given below:

1) Chickasha, Oklahoma

2) Oxford, Mississippi

3) Blacksburg, Virginia

4) Muddy Branch, Maryland

The findings of this analysis are summarized in the following:

1) Substantial hydrologic information can be measured from
   LANDSAT imagery. The parameters identified and measured were:
   surface water bodies, surface cover classes, channel lengths,
   and watershed area. Both single-band and color composite im-
   agery were examined; the latter offered much more information
   and greatly facilitated analysis.

2) Of particular value were seasonal LANDSAT observations. For
example, the October imagery showed the watersheds when vege-
tation density was low; this made the higher-order streams
visible. More channels could be measured from the Chickasha,
Oklahoma, image than appeared on the U.S.G.S. topographic map
at the same scale. LANDSAT imagery clearly shows that ef-
fective drainage density varies cyclically throughout the year.

3) It became apparent that published records do not reflect cur-
rent surface cover conditions, since the watershed's land use
typically alters with time. The October, 1973, LANDSAT imagery
demonstrated that surface cover for the Chickasha Basin had
changed from that described in the latest published data (1967).

4) The Oxford and Blacksburg watersheds were used to evaluate the
discriminability of stream courses, forest cover, surface water
and impermeable areas from LANDSAT images. The relative value
of each of the four MSS bands was assessed; Band 7 was found
most useful for surface water, while Band 5 offered more detail
in vegetated areas. It was concluded, though, that composite
imagery optimized the contributions of all bands.

5) A complete hydrologic land use analysis was performed using
color composite imagery for the Muddy Branch basin in Montgomery
County, Maryland. The accuracy of the process was verified by
comparison with aerial photography ground truth. The results
are summarized in Table 3 . Overall error was about 6%, ac-
ceptable for computation of surface cover factors of hydrologic
models.

TABLE 3

SURFACE COVER CLASSIFICATION RESULTS, MUDDY BRANCH BASIN

	AREA LANDSAT	% OF WATERSHED	AREA AERIAL	% OF WATERSHED	INVENTORY ERROR
Urban	557 ha	11	649 ha	12	-14%
Forest	1.242 ha	24	1,292 ha	23	- 4%
Lakes	30 ha	1	29 ha	1	+ 3%
Soil	575 ha	11	547 ha	10	+ 5%
Fields	2,852 ha	54	3,028 ha	55	+ 6%

IV. APPROACH TO THE PRESENT EFFORT

The current phase of this effort brought the prior work to a conclusion through four tasks:

Task 1   The complete development of the routing model.

Task 2   The derivation of hydrologic parameters from LANDSAT imagery for an additional watershed, making a total of five for which such analysis has been performed.

Task 3   The documentation of procedures for extracting hydrologic information from LANDSAT imagery.

Task 4   Demonstration of the procedures and model to a selected group of users.

Figure 1 is a flow chart showing the objectives set out for this phase.

Task 1 constituted the synthesis of a routing module for the planning model. This has been completed and programmed in FORTRAN IV for operation on small-capacity digital computers. The model features user-interactive operation and amenability to present and potential inputs from satellite remote sensors.

A summary of its derivation is presented in Section VI. (A more detailed derivation is included in the Appendix). Task 1 culminated in the simulation of a peak runoff event as taken from actual gage records; this is also described in Section VI.

Task 2 involved the hydrologic land use classification of the Bucklodge Branch watershed in Montgomery County, Maryland. The techniques developed for Task 3 (described below) were applied to cover

FIGURE 1:   FLOW CHART OF CURRENT PHASE

```
+-------------------------+        +-------------------------+
| COMPLETION OF ROUTING   |        | DOCUMENTATION OF IMAGERY |
| MODEL DEVELOPMENT       |        | ANALYSIS PROCEDURE       |
+-------------------------+        +-------------------------+
           |                                    |
           +-----------------+------------------+
                             |
                             v
                  +-------------------------+
                  | VALIDATION OF ROUTING   |
                  | MODEL AND ANALYSIS PRO- |
                  | CEDURE                  |
                  +-------------------------+
                             |
                             v
                  +-------------------------+
                  | EXPOSURE OF MODEL AND   |
                  | PROCEDURES TO SELECTED  |
                  | USERS                   |
                  +-------------------------+
```
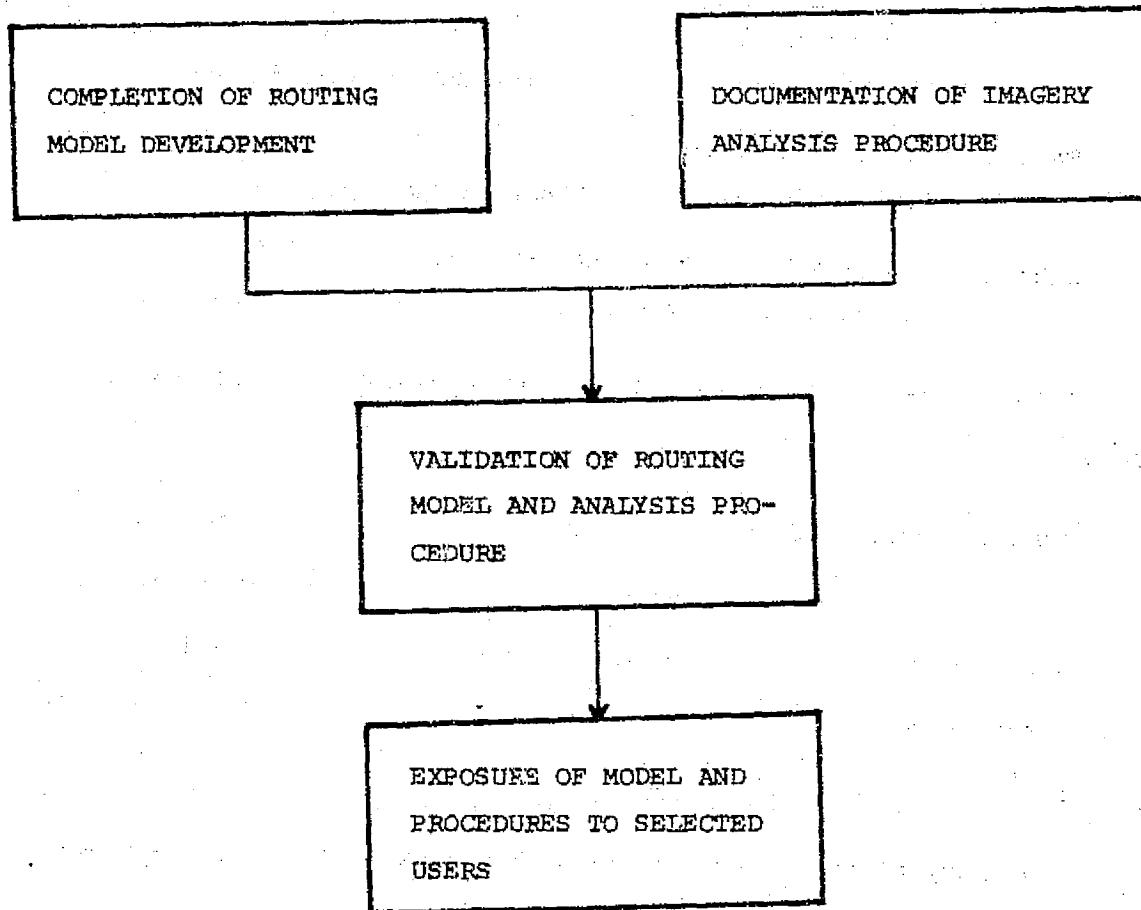
classification of Bucklodge Branch. This task also included the derivation of model parameters from the remotely sensed information. Results are reported in Section VI.

Task 3 resulted in the development of generalized procedures for extraction of quantitative information from LANDSAT imagery through simple visual analyses. The findings, given in Section V, showed that relatively uncomplicated techniques can yield results adequate for hydrologic modelling.

The final task included identification of prospective user groups and exposure of the model and associated analysis procedures to them. A summary of those activities is presented in Section VII.

V. PROCEDURES FOR EXTRACTION OF HYDROLOGIC DATA FROM LANDSAT IMAGERY

The quantities of rainfall which eventually become stream discharge depend in large measure upon the character and condition of the land surface over which it must run. Rain falling on a watershed is subjected to the retardant forces of the surface cover; this retardation, in turn, regulates the fractions of the water mass which run overland, infiltrate or are evaporated. A rural watershed covered with thick grass and trees, for example, will have a much different response to a peak rain event than will its urbanized counterpart.

Figure 2 exemplifies this effect. The curve shows the impact on runoff peak of altering the surface complex (as approximated by the S.C.S. curve number). Points on the curve were generated using a recorded rain event input to a 150 square kilometer basin in the region of Tuscany, Italy.* The sensitivity is marked. Figure 3, similarly, demonstrates the effect on the discharge peak of seasonal change, in this example, that of cultivating a portion of the watershed. Again the results are pronounced. Two conclusions can be made:

1) Surface cover is a significant driver of peak discharge event.

2) The provision of periodic land cover information can be of value to the hydrologic modeller.

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* This watershed is currently being modeled for the government of the Region of Tuscany, Italy. The modeling techniques were derived from the present NASA — sponsored effort.

FIGURE 2: SENSITIVITY OF DISCHARGE TO SURFACE COVER

-17-
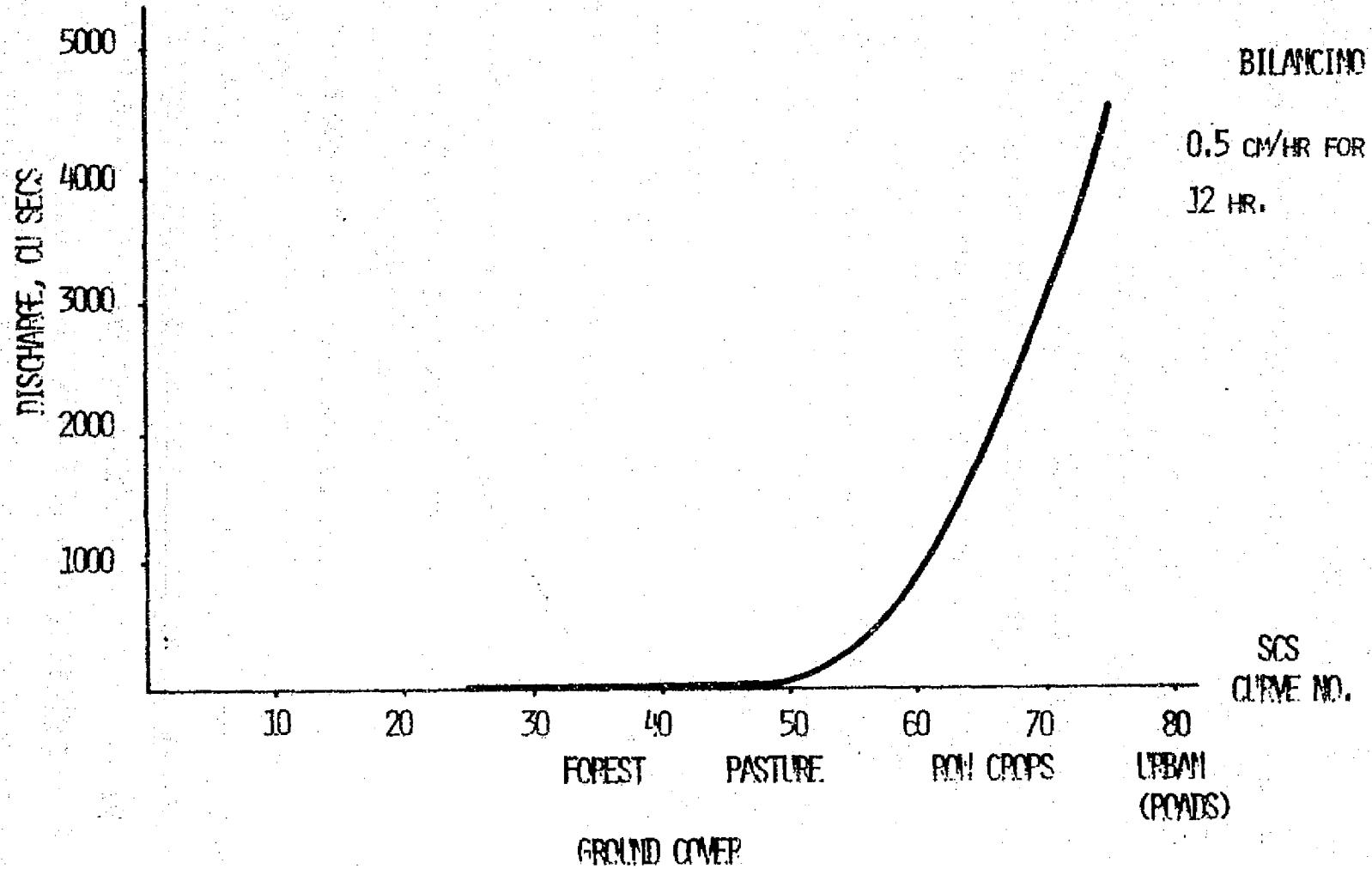
FIGURE 3   SENSITIVITY OF WATERSHED RESPONSE TO CHANGES IN VEGETATIVE COVER
FOR THE SAME PLANNING PAIR
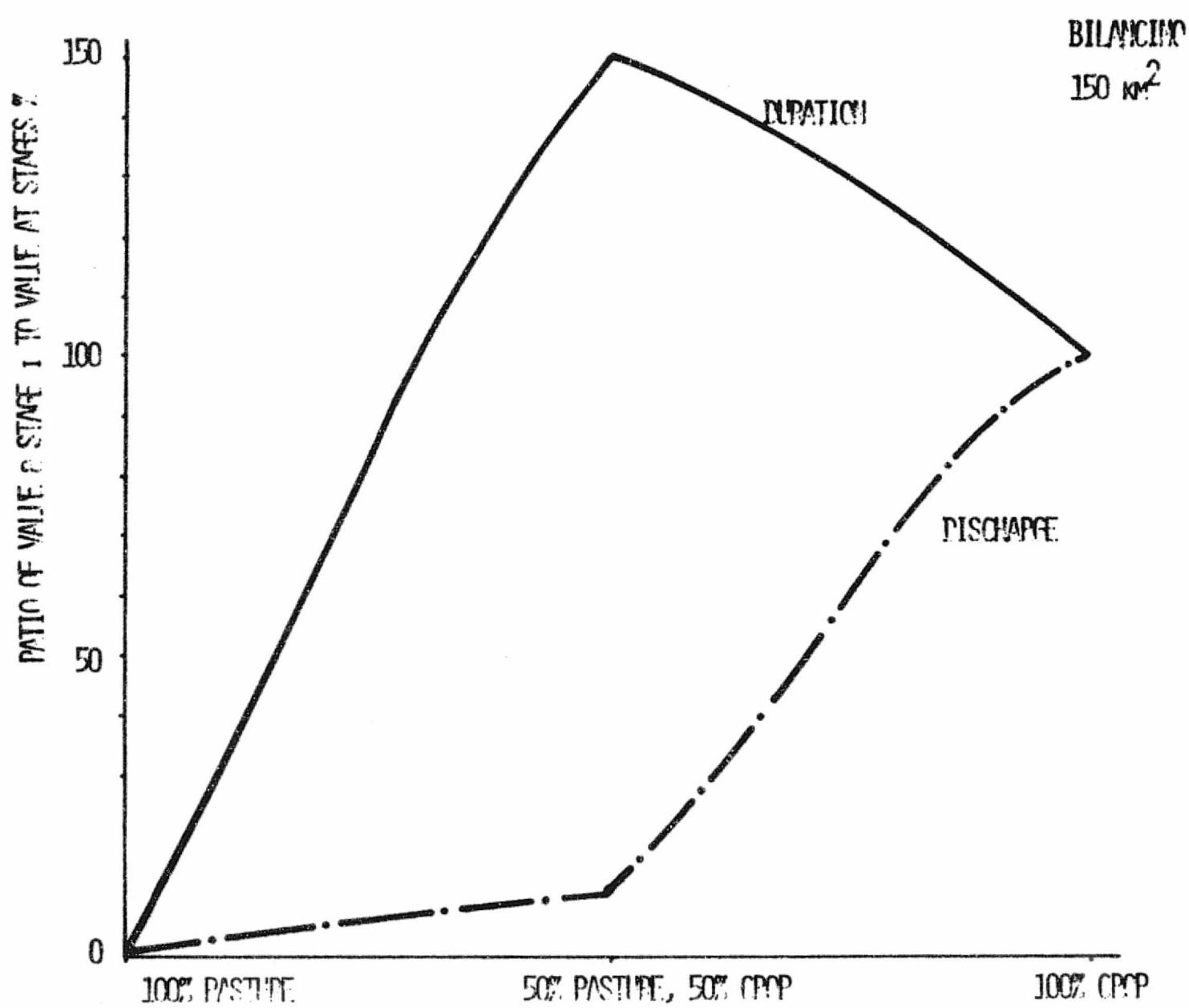
Prior work in remote sensing for hydrology has shown that surface cover can be derived from presently available LANDSAT imagery. A problem with reducing potential to practice, however, has been the absence of standard procedures for extraction of required data by uncomplicated, inexpensive, yet accurate, means.

One objective of this effort was the development of procedures for utilizing LANDSAT data to determine watershed surface cover. An important result is that the procedure eventually developed is applicable not only to the specific model developed herein, but can be generalized to all hydrologic models.

5.1 Importance of Surface Cover to Hydrologic Models

For reasons just discussed, all but the simplest hydrologic models take surface cover into consideration. Specific implementations vary but generally include the following:

a. Computation of initial detention storage

b. Calculation of surface resistance to overland flow

c. Division of the rainfall mass into its overland and infiltrated fractions

d. Estimation of potential evapotranspiration

e. Quantification of the effects of impermeable areas

Figure 4 summarizes the surface cover inputs to several widely-used hydrologic models. It is clear that a substantial amount of surface-related information is required.

MODELS	SURFACE COVER	LAND USE/ LAND USE CHANGE	SURFACE WATER	IMPERMEABLE AREAS
USDAHL-70/74	■	■		
USGS				■
UTAH STATE U.	■	■	■	■
STANFORD MODEL	■		■	
TEXAS MODEL	■		■	
NOAA HYDRO 14	■		■	■
NOAA HYDRO 17		■		
API	■	■		
SSARR		■	■	
COSSARR		■		
S.C.S. TR-20	■	■		
MITCAT	■	■	■	■

FIGURE 4: SURFACE COVER VARIABLES OF WATERSHED MODEL

For these requirements to be filled by LANDSAT, the frequency and resolution of the LANDSAT-derived data must be sufficient to meet model demands. With respect to the first point, LANDSAT can provide a new surface cover picture every nine to eighteen days. This frequency meets and exceeds all the requirements of current models, even when cloud occultation is factored in.

The resolution of land cover detail required by the models varies, but is generally consistent with the current capabilities of LANDSAT sensors. The exceptions are those models designed to analyze intra-urban hydrology; satellite data will be of limited applicability here. For those models suited to evaluation of larger watersheds, most requirements can be met through a LEVEL I* land use classification, which can be accomplished remotely. The modeller must be able to distinguish between:

    a.   Urbanized areas

    b.   Agricultural (cropped) areas/fallow

    c.   Surface Water

    d.   Pasture

    e.   Forests

---

*(As defined in, "A Land-Use Classification System for Use With Remote Sensing Data," U.S.G.S. Circular 671, Anderson, Hardy, and Roach, 1972)

This level of detail will permit computation of friction factors such as Manning's "n," mensuration of impermeable areas; calculation of surface water area; etc.

5.2 Alternative Techniques for Analysis of LANDSAT Imagery

Because LANDSAT data is produced in two forms, computer compatible tapes (CCT's) and "photographic" images, two options for its analysis exist - computer and visual classification/mensuration. The first involves the development of mathematical/statistical algorithms for separation of themes based upon the relative output of each of the sensors. Visual analysis is the same with the exception that the algorithm is mental. The interpreter segregates on the basis of the individual or summed reflectance levels of the Multispectral Sensor Bands.

What are the advantages/disadvantages, if any, of either procedure? Our work in hydrology, and other application areas, has made obvious a number of factors making visual analysis preferable for "complex" scenes and low-cost applications. Principal among these are:

Training Sample Criteria

Computer classification and mensuration requires the establishment of a number of training samples. These should be "homogeneous" samples, containing at least a minimum number of pixels. With visual analysis, it is possible to minimize the training field requirement; it is also easier to account for variations within a theme which would result in errors with computer classification.

Maximization of Multi-Temporal Properties of LANDSAT Imagery

In hydrology, as well as agriculture, the use of multi-date imagery

has proved advantageous. Visual analysis facilitates the simultaneous
evaluation of images from different seasons, years, etc., at low cost.

Ground Truth

In most settled areas, the scales of features vary significantly.
The relatively low, 66 meter average resolution of LANDSAT causes
boundary effects which distort the identification and mensuration of
areas less than several tens of acres, if performed by automatic means.
Only the visual overlay of aerial imagery or maps against LANDSAT imagery
corrects this problem. Projection of visual images at scales which
can be comfortably observed greatly facilitates scale matching.

Accuracy of Results

Except for LANDSAT scenes taken at the correct seasons when reflectance
differences among the various ground covers are most pronounced and in
which the features to be identified are extensive compared to the LANDSAT
pixel dimensions, automatic classification exhibits considerable errors.
Visual analysis employing one or more of the techniques indicated above
(multitemporal, superposition with aerial photography), can result in
significantly improved accuracies.

Equipment Requirements/Costs

The initial capital cost of visual analysis equipment (projectors,
zoom transfer scopes) is considerably lower than that of digital processing
equipment. For "complex" scenes, visual analysis has been found in this
effort to cost on the order of 10% of computer analysis at equal performance.
It is concluded that at the present state of the art, visual analysis
techniques are preferable for small users, because they are more likely
to utilize LANDSAT imagery if the initial costs and skills levels required

are kept as low as possible.

Even with simple visual means two problems still constitute impedi-
ments to the practical use of LANDSAT imagery: 1) the lack of a standard
procedure; and 2) the unavailability of projection/analysis devices
amenable to complete analysis of satellite imagery at low cost. ECOsystems'
effort has resulted in techniques for solving both these problems.

A device for easy analysis was developed and tested* which is suited
to LANDSAT scales and resolutions. It is described in Appendix B.

The following describes a recommended procedure for deriving
quantitative hydrologic data from the MSS imagery.

5.3 Visual Extraction of Hydrologic Land Use from LANDSAT Imagery

The preceding sections have described the uses of surface cover
data by hydrologic models, and indicated that many are obtainable from
LANDSAT imagery. It is significant, in addition, that the extraction
of these data can be accomplished through simple and inexpensive visual
means, procedures similar to those used in analysis of aerial photographs.
The development of a certain amount of expertise on the part of the
interpreter is necessary, but the level required is not prohibitive.
The most important concern is that a careful and consistent analysis
procedure be adhered to, such as that described herein.

5.3.1 Land Use Information Content of the Four LANDSAT Bands

In order for LANDSAT data to be useful in hydrologic analysis:

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* The device was developed on ECOsystems' own funds, but utilizing
to the fullest the experience garnered in this NASA - sponsored
effort.

resolution of the sensors must be sufficient to provide the required level of classification and area measurement; and, the optimum spectral bands must be chosen for the surface feature under study.

With respect to the first criterion, the minimum resolvable area of the LANDSAT sensors is of order 0.4 hectares (1 acre). The applicability of LANDSAT, therefore, will be optimized where the unit of analysis is sufficient, i.e. in medium to large-sized basins predominated by rural land use; it is in these basins, though, where gage records are typically less detailed and where modelling can have large benefits (snowmelt analysis, water works sizing, flood forecasting).

With respect to the second criterion, no single LANDSAT band can distinguish all land use classes well enough to meet the requirements of hydrologic modelling. However, the output from the four sensors taken individually and in sum do provide sufficient information. Each sensor sees a distinct spectral range and, therefore, receives different radiance levels from a particular object. For the purposes of thematic segregation, it is preferable that a sensor see a theme at one extreme of reflectance (i.e., very high or very low) while giving the opposite value for all other themes. This maximizes contrast and likewise the separability of the theme. Again, no single spectral band can accomplish this ideal case, but an examination of the imagery shows that hydrologic land use classes can be separated.

For example, in LANDSAT Band 7 (0.8 - 1.1μm) surface water appears very dark while its surroundings are generally much lighter whereas for Band 5, forested areas appear dark. Figure 5 illustrates this.

FIGURE 5

REFLECTANCE CHARACTERISTICS OF MSS BANDS

MSS BAND 5
(0,6 - 0.7 μm)
FOREST - DARK

MSS BAND 7
(0,8 - 1,1 μm)
SURFACE WATER - DARK
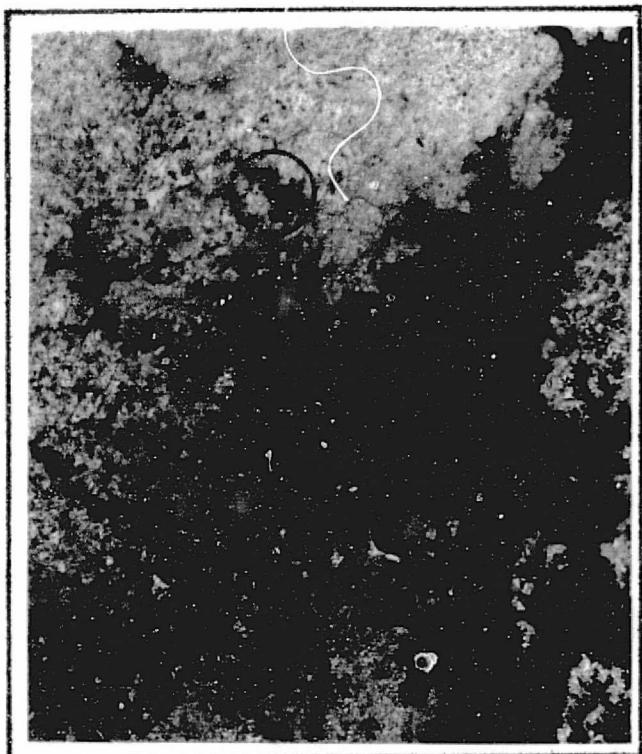
Table IV summarizes exemplary radiometric data and indicates which
bands appear preferable for a given theme. The values, derived from
imagery from the Baltimore-Washington area, show where the land uses fall
on a fifteen-step gray scale. (A value of 1≈ 100% reflectance; 15 ≈
0% reflectance). Themes will be most easily separated where the variance
is small and where the other themes have different values.

5.3.2 Use of Composite Imagery

The utility of LANDSAT imagery can be augmented by combining the
individual bands into composites. The addition of color to each band
facilitates the separation of surface themes, because it allows the
analyst to see the information contained in all bands simultaneously.

A simple, low cost procedure for color encoding individual black
and white images and compositing them is available in the diazo process.
Its best usage, as developed by ECOsystems, is to produce plastic transparencies
in shades of a single color directly from LANDSAT 9" x 9" images. To ac-
complish this, the black and white image is sandwiched with a sheet
of diazo film and exposed to ultraviolet light. The film is

TABLE IV

	BAND 4	
	OCT. '73 IMAGE	JUNE '73 IMAGE
Surface Water	5-10	3-4
Urban	1- 7	1-2
Forest	10-11	7-8
Fields/Agricultural	4-13	1-9

	BAND 5	
Surface Water	10-14	9-10
Urban	1- 4	1- 2
Forest	10-11	10-11
Fields/Agricultural	1- 7	1-12

	BAND 6	
Surface Water	15	15
Urban	4-12	8-10
Forest	8- 9	5- 6
Fields/Agricultural	4-12	4-10

	BAND 7	
Surface Water	15	15
Urban	10-11	10-11
Forest	7- 8	2- 5
Fields/Agriculture	2-11	1-11
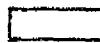
☐ - indicates best single band for given theme

then developed by simple equipment which exposes it to ammonia vapors.
Figure 6 exemplifies the process product: a diazo positive of a single-
band - LANDSAT image processed in cyan. The procedure is repeated for
the other bands producing each band in a different color. Finally, the
diazo transparencies are overlayed, registered, and glued together to
form the composite image. Figure 7 is a contact print of the resultant
composite.

Several advantages to image analysis with diazo transparencies have
been found:

1. The costs are very low, especially when compared to computer-
   aided classification techniques. The exposure and develop-
   ment unit can be purchased for approximately $500 to $1,000.
   The materials cost for composite transparencies is less than
   one dollar.

2. The diazo film yields a faithful positive reproduction of the
   original image. Very little detail is lost, and processing
   time is short. A composite transparency can be produced in
   under a hour.

3. By varying exposure times and film color, images can be
   "tuned" to accent desired features while depressing others.
   This significantly augments the separability of surface
   themes. Several composites can be prepared for a watershed,
   each of which optimizes the visibility of a specific land
   use.

5.4 Recommended Procedure for the Visual Analysis of LANDSAT Composite
    Imagery

The visual analysis of imagery for hydrologic land use should proceed
in six steps:
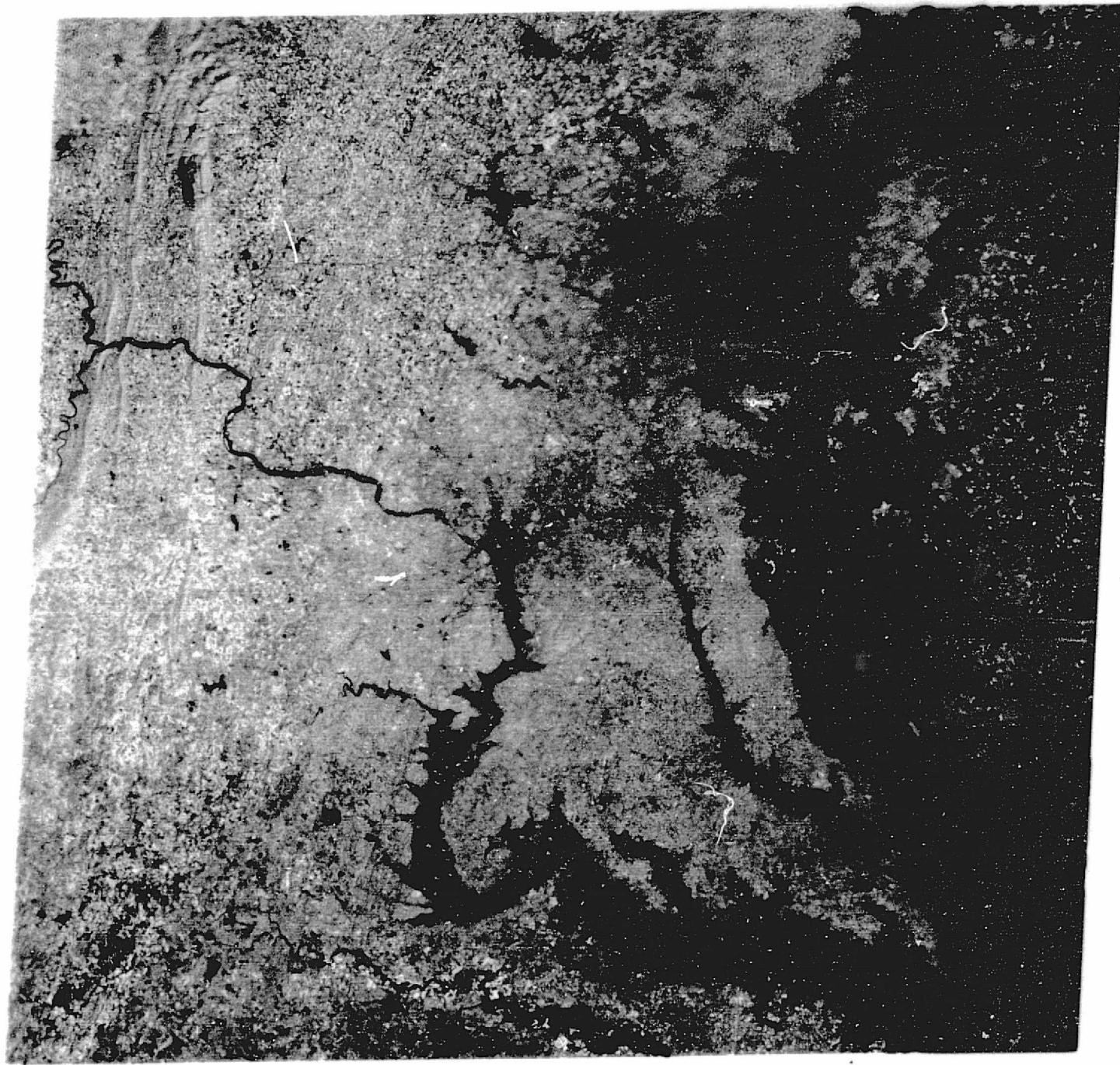
FIGURE 6

BAND 7 DIAZO TRANSPARENCY ENCODED
IN CYAN, 6 OCTOBER 1973

FIGURE 7

SECTION OF CONTACT PRINT OF THREE BAND

DIAZO COMPOSITE, 6 October 1973

BAND 4 - YELLOW

BAND 5 - MAGENTA

BAND 7 - CYAN

1) Preparation of "tuned" Diazo Composites

2) Image Projection/Ground Truth Overlay

3) Watershed Delineation

4) Analysis of Ground Truth

5) Segregation of Surface-Cover Themes

6) Quantification of Hydrologic Parameters

5.4.1 Preparation of "Tuned" Diazo Composites

As noted earlier, no single LANDSAT band contains all the hydrologic information; each sensor maximizes the reflectance of the surface in a different spectral range. Full advantage of these reflectance differences has generally not been exploited in visual analysis: rather, past work has relied mostly upon LANDSAT's geometric properties - identification of shape and form from single color composites.

The diazo compositing process affords the analyst the opportunity to optimize the value of radiometric differences. Consider the following example: Band 5 (0.6 - 0.7μm) receives low reflectance from vegetation since these wavelengths are absorbed by chlorophyll. Band 7 (0.8 - 1.1μm), in contrast, receives nearly 50% of the incident radiation from mature green vegetation. This phenomenon can be exploited to discriminate vegetation.

Suppose that the watershed under study contains heavily vegetated areas. Is it possible to assign a desired color to these areas in preparing the composite.

If it is desired that these vegetated areas appear red, it is only necessary to encode the Band 5 diazo positive in red (and/or Band 4, if

it is used, since the two are correlated) and to develop Bands 6 and 7

in contrasting colors. The red vegetated areas of Bands 4 and 5 will show

through the equivalent sections of Bands 6 and 7 which will be clear.

The result is a composite "tuned" to vegetation.

Thus, by referral to the relative reflectances of land use classi-

fication, such as shown in Table 4, the analyst can compose his imagery

to make more obvious the themes he wishes to identify. The technique

described is valid for themes which provide high contrast (low or high

reflectances simultaneously present). A modification of the process

allows separation of themes whose reflectances lie closer together (lower

contrast). It is a property of diazo imagery that increasing exposure

time decreases the content of the image; i.e. a long exposure time drops

out themes with high reflectance (low image density). A positive image

can be color-encoded in a given color and exposed to the point where all

areas with lesser density than those desired are eliminated. This pro-

cedure is then repeated with the equivalent negative image, but in a

contrasting color. When the two images are overlayed, the subject then

will appear in the color produced by combination: surrounding areas

will be in pure hues. Figure 8 demonstrates the results.

The two techniques described above separate all but themes with

very low relative contrast. To further improve the discrimination

between these, a third option is the use of multi-temporal imagery.

For example, forested areas and fields can have similar reflectances

in all the MSS bands. Fields, however, are far less likely to display

a signature which remains constant over the year. Figure 9 depicts an

example. Note that in the February image the forest has lost its

FIGURE 8

TUNED DIAZO IMAGE - URBAN AREAS
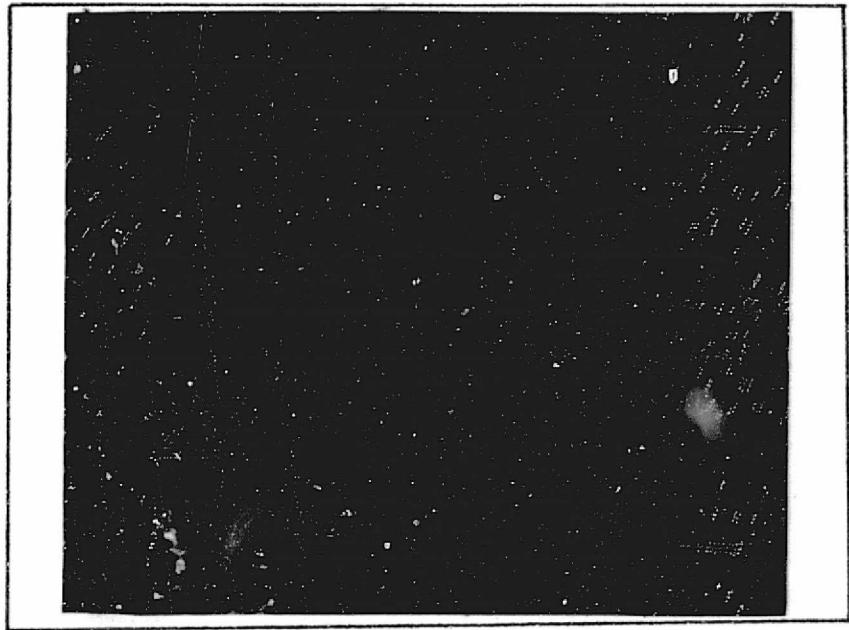
FIGURE 9: SEASONAL CHANGE; IN FOREST SIGNATURE

OCTOBER 1973

LANDSAT 3 BAND COMPOSITE

FOREST CONTRAST LOW

FEBRUARY 1974

LANDSAT 3 BAND COMPOSITE

FOREST CONTRAST HIGH

similarity with fields.

A recommended procedure for integrating these techniques is to first develop a standard composite of bands and colors such as Band 4 (yellow), Band 5 (magenta) and Band 7 (cyan). The analyst should then separate all identifiable themes; the resultant classification can then be confirmed or adjusted by subsequent analysis of composites tuned to a particular theme from different seasons.

5.4.2 Image Projection

Land use classification to Level 1-2 requires significant magnification of the 1:1,000,000 scale LANDSAT imagery. This has previously been a drawback of visual analysis hardware - devices which could permit enlargement to greater than about 10X have been very expensive. The cost can be greatly reduced, however, as exemplified by the imaging system developed for such analysis by ECOsystems. Experience with this system has shown that magnifications of about 40X are convenient for land cover analysis, since they permit the direct overlaying of 1:1,000,000 LANDSAT images upon USGS 1:24,000 topographic maps. To insure the color-fastness of the images during analyses, color slides should be made from the diazo composite. The slides can be made to include as large an area as desired, but it is preferable to reproduce the diazos at one-to-one scale. The area represented in a 35-millimeter, 1:1 from a 1:1,000,000 LANDSAT image will be approximately 86,500 hectares. Larger watersheds can be analyzed in sections.

The slides are made with a 35 millimeter single lens reflex camera equipped with a bellows. The diazo composite is illuminated from behind by a light source matched to the color temperature of the slide film used. The photographs are taken with the camera mounted on a copy stand. Once exposed, nearly all slide films can be developed "in-house" using inexpensive chemistry. The time required from exposure to projector-ready slide is less than two hours.

Finished slides are mounted in the imaging system and projected. As shown in Figure 10 , the analysis table is equipped with an overhead mirror which reflects the image onto a work surface. The LANDSAT image can thereby be superimposed over maps or aerial photographs. A zoom control allows the scales of the projected image and ground truth to be matched.

5.4.3 Watershed Delineation/Ground Truth Overlay

Analysis of hydrologic land cover begins with the demarcation of the boundaries of the watershed. Except in regions of very high relief, some ancillary information is generally required. This is readily available in the form of USGS topographic maps. Stereo aerial photographs, where available, can also be used. The watershed ridge line is first traced on the map. The LANDSAT image is projected over the map and aligned using roads, rivers, lakes, or other prominent features for reference. A sheet of tracing paper is placed over both and the ridge line drawn on it. The map is then removed.

5.4.4 Analysis of Ground Truth

There are a number of widely-available sources of ground truth which can be valuable aids to the interpretation of satellite imagery.

FIGURE 10

ECOSYSTEMS IMAGE ANALYSIS DEVICE

PROJECTION
UNIT

ANALYSIS
TABLE
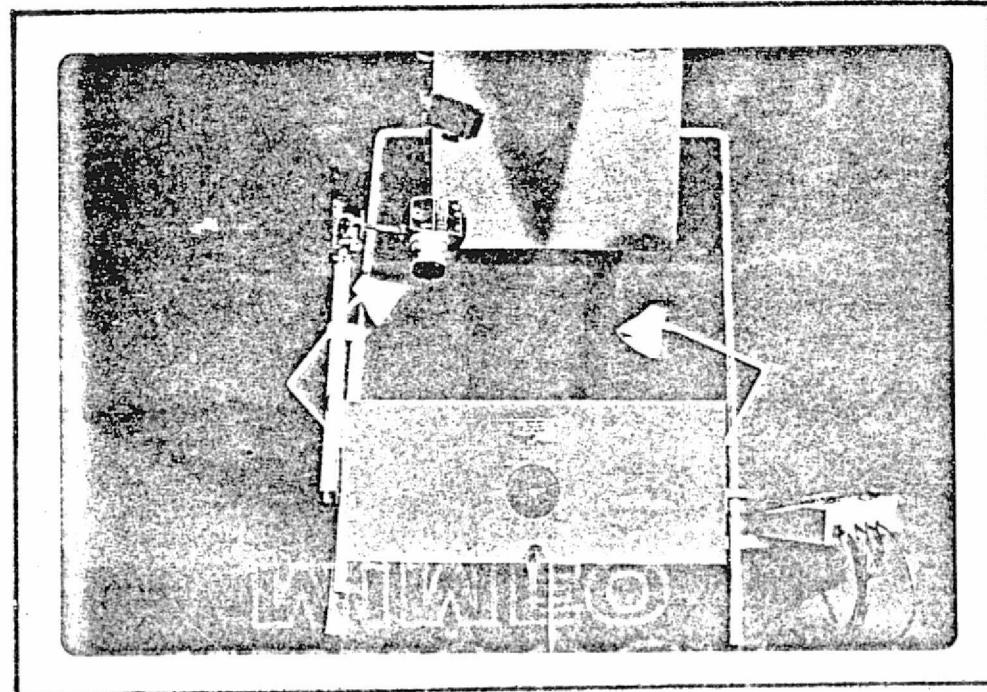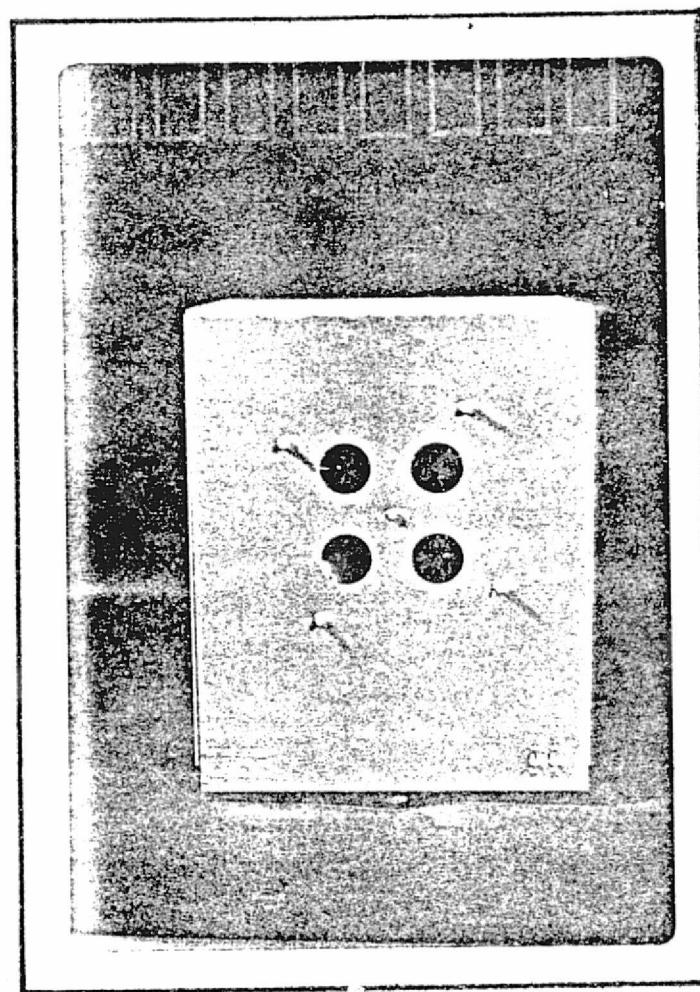
Among these are:

1) topographic maps (USGS)

2) soil surveys (SCS)

3) aerial photographs

Topographic maps, though often dated, contain some land cover information. Specifically, forested areas, lakes, streams and urban areas are called out. Soil Conservation Service maps are most valuable to estimation of the subsurface characteristics of a watershed but also show streams, roads, surface water. Many have the soil classes drawn upon aerial photographs which may be used as ground truth if better ones are not obtainable. Low altitude aerial photographs are the best source of ground truth, but are also the more expensive and least available.

What are the optimum uses of ground truth, and how would one proceed to analyze land cover without it? In the absence of any ancillary data whatsoever, it would be necessary to rely totally upon the radiometric characteristics of the LANDSAT sensors. Even in this case, it is possible for a great deal of land cover information to be culled out. Visible themes such as rivers and lakes, some urban areas, and forests can be identified by their shape and form. An interpretor with some knowledge of the study area and of the spectral properties of land use themes could add another level of information. This, in effect, would be the same as checking LANDSAT data against a training field. Familiarity with the seasonal or phenologic progressions of vegetation is also most valuable.

A competent interpreter can generally adequately classify hydrologic land use to Level 1-2 using only LANDSAT imagery. The existence of

certain types of ground truth facilitates the process and should be
taken advantage of. Maps and photographs, even if outdated, can be used
to verify that an area classified as forest is, indeed, forest. If such
fact can be confirmed within the watershed, or even in a nearby location,
the results of these "tests" can be extended over the study area, e.g.
if a red-blue area in the LANDSAT image is determined to be forest,
areas of like color can also be classified as forest. The resultant
classification can be spot-checked where the presence of true forest
areas is known.

Prior to evaluation of the LANDSAT images, all available ground
truth should be collected. The data obtained should be summed into a
base map for the basin. All surface features discernible from the
ground truth should be designated on the map. In the ideal case, ground
truth is sufficiently complete to designate a gross,even though mostly
outdated, land use map for the entire basin; the function of the LANDSAT
data, in this case, is to update the older information and to provide
the important seasonal information which it lacks.

5.4.5 Classification of LANDSAT Themes

The next step in surface cover analysis is the actual classification
of themes from the diazo composite. The image has been projected on the
work surface and the watershed boundaries established. The analyst must
then determine how many separable themes, or colors, exist within the scene.
Figure 11 exemplifies the process. The analyst should make a tracing of the
themes which are identifiable. Once drawn, it is helpful to assign an ident
fier to each area delineated and identified; it is suggested that this be
accomplished through comparison with a set of standard color chips such

FIGURE 11

SEPERATION OF LAND USE THEMES
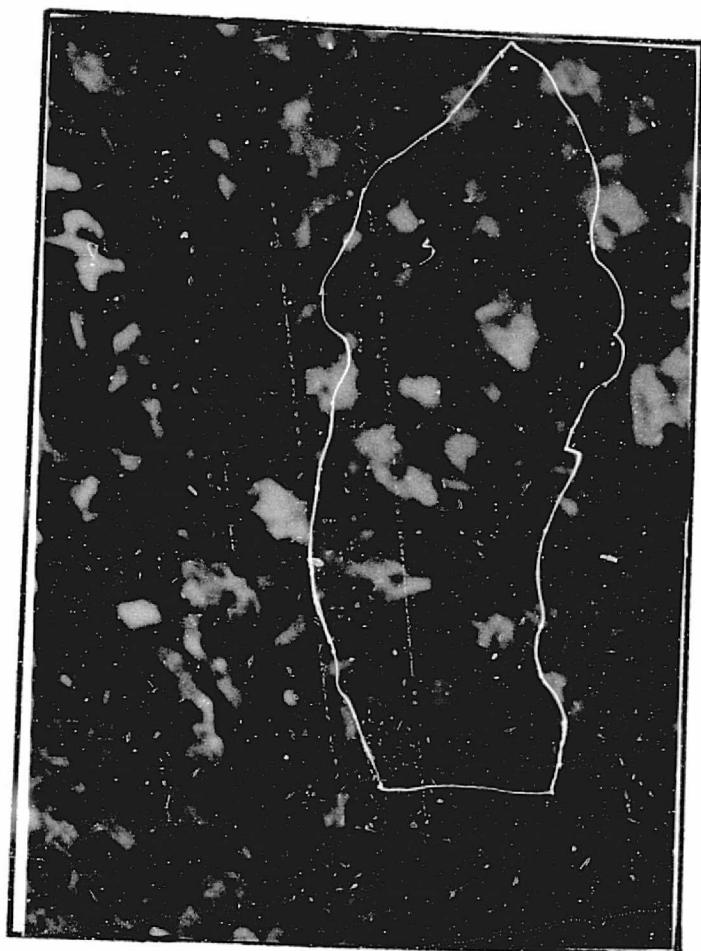
MUDDY BRANCH BASIN
LANDSAT
6 OCT. 73

■ Soil

▨ Urban

▣ Forest

☐ Fields

☐ Lakes
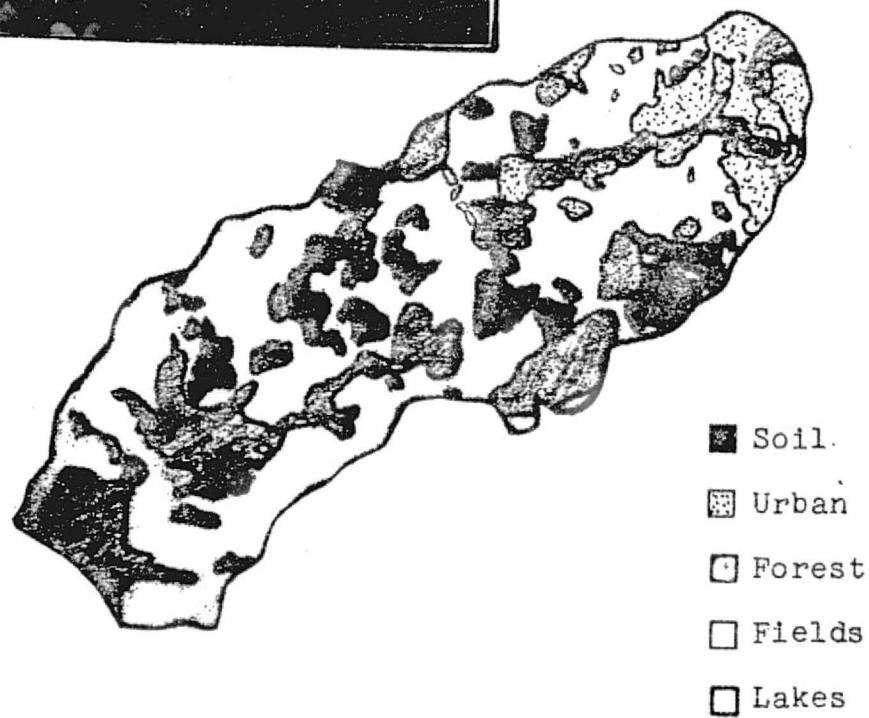
as those used in aerial photographic interpretation. Each separable
color is thereby given a unique label; this insures repeatability and
also facilitates validation by other interpreters.

At this point the analyst has a map divided into color themes
but has not as yet identified what the colors represent. To do this, he
refers to the available ground truth; selects a test area from within
each color class; compares it to the maps or photos, and assigns the
area to a land use designation as in Figure 12. The resultant land use
map should be regarded as still tentative. The classifications are
subject to modification using composites of different composition, i.e.
different tuning, or from different seasons. Generally, initial classifi-
cation reveals differences between the LANDSAT imagery and the ground
truth due to changes more recent than are reflected in the maps or
photos; these can be confirmed by reference to additional images.

The result of multiple-image classification will be a hydrologic
land use map suitable for the derivation of quantitative model parameters.

5.4.6 Quantification of Hydrologic Parameters

With the land use map in hand, the derivation of model parameters
can proceed as it would using any source of surface cover data. The
exact procedure will vary with the model used; the following paragraph
describes a generalized technique used by several models - the computa-
tion of an average value of Manning's "n" for a subwatershed.

Planning models often require the division of watersheds into
hydrologically homogeneous sub-areas. The criteria for defining

FIGURE 12: CLASSIFICATION OF LAND USE THEMES
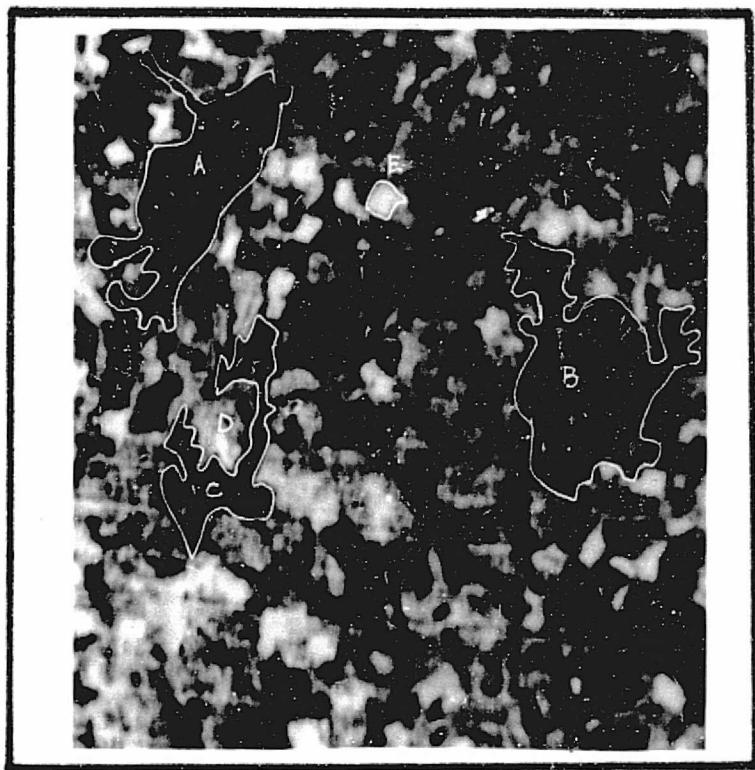
LANDSAT

3 BAND COMPOSITE

OCTOBER 1973

A, B, and C Indicate Forest

D and E Indicate Fields

AERIAL COLOR - IR

DECEMBER 1973
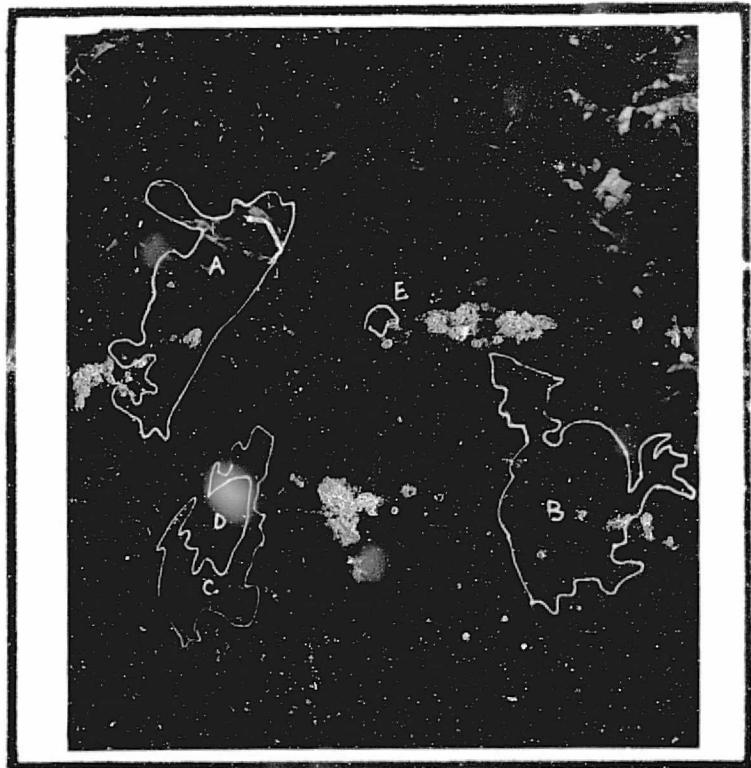
homogeneity include topography, soil characteristics, and surface cover.
Typically, maps of each are prepared and compared in overlay fashion.
The modeller then divides the watershed to give the optimum uniformity
among these three parameters. Figure 13 demonstrates the process.

Once the homogeneous sub-areas are established, an average set of
parameters is assigned to each. With respect to surface cover, an
average surface friction factor, such as Manning's "n," is computed
for every sub-area. Figure 14 shows how this is accomplished from the
LANDSAT map as well as from aerial photography. First, the sub-areas
are delineated on the land cover map. Then the percentage of its area
covered by each use is computed using a calibrated grid, as shown, or a
planimeter. Finally, the percentages computed are compared to a table
of values for Manning's "n" as reproduced in the figure. Their computed
weighted average becomes the average friction factor for the sub-area.
Parallel analyses of LANDSAT and aerial images, performed during this
effort, yield nearly identical values for surface friction.

These values become direct inputs to planning models. The following
section demonstrates the application of the techniques described to an
actual watershed.

GURE 13   DIVISION OF A WATERSHED INTO HYDROLOGICALLY HOMOGENEOUS
          SUB-AREAS

FOREST, n = .10
FIELDS, n = .035
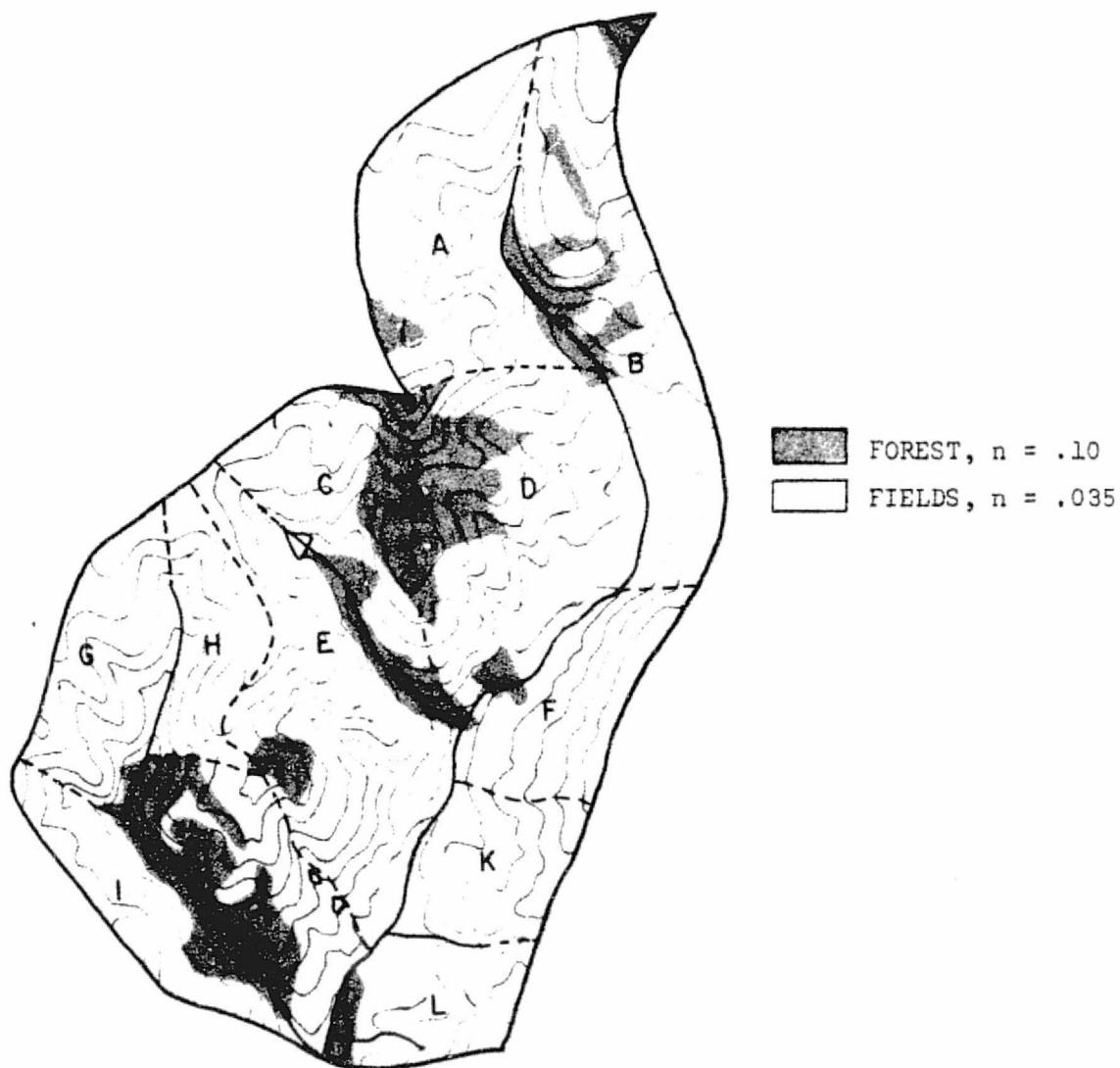
SUBBASIN	AVG. "n"	AVG. SLOPE M/M	AVG. INFIL. (range) cm/hr.	AVG. SOIL MOISTURE CAP. cm.
A	.040	.050	2.5 - .25	7.6
B	.056	.055	5.1 - .5	7.6
C	.068	.055	.25 - .03	1.3
D	.056	.075	1.3 - .05	2.5
E	.044	.080	1.3 - .05	2.5
F	.038	.080	5.1 - .5	7.6
G	.038	.070	.25 - .03	1.3
H	.035	.110	1.3 - .05	2.5
I	.053	.105	1.3 - .05	2.5
J	.064	.085	5.1 - .5	7.6
K	.035	.060	.25 - .03	1.3
L	.045	.055	1.3 - .05	2.5

FIGURE 14: ASSIGNMENT OF HYDROLOGIC PARAMETERS

LANDSAT COMPOSITE
OCTOBER 1973

1 = FOREST

2 = FIELDS

3 = URBAN

AERIAL COLOR IR
DECEMBER 1973
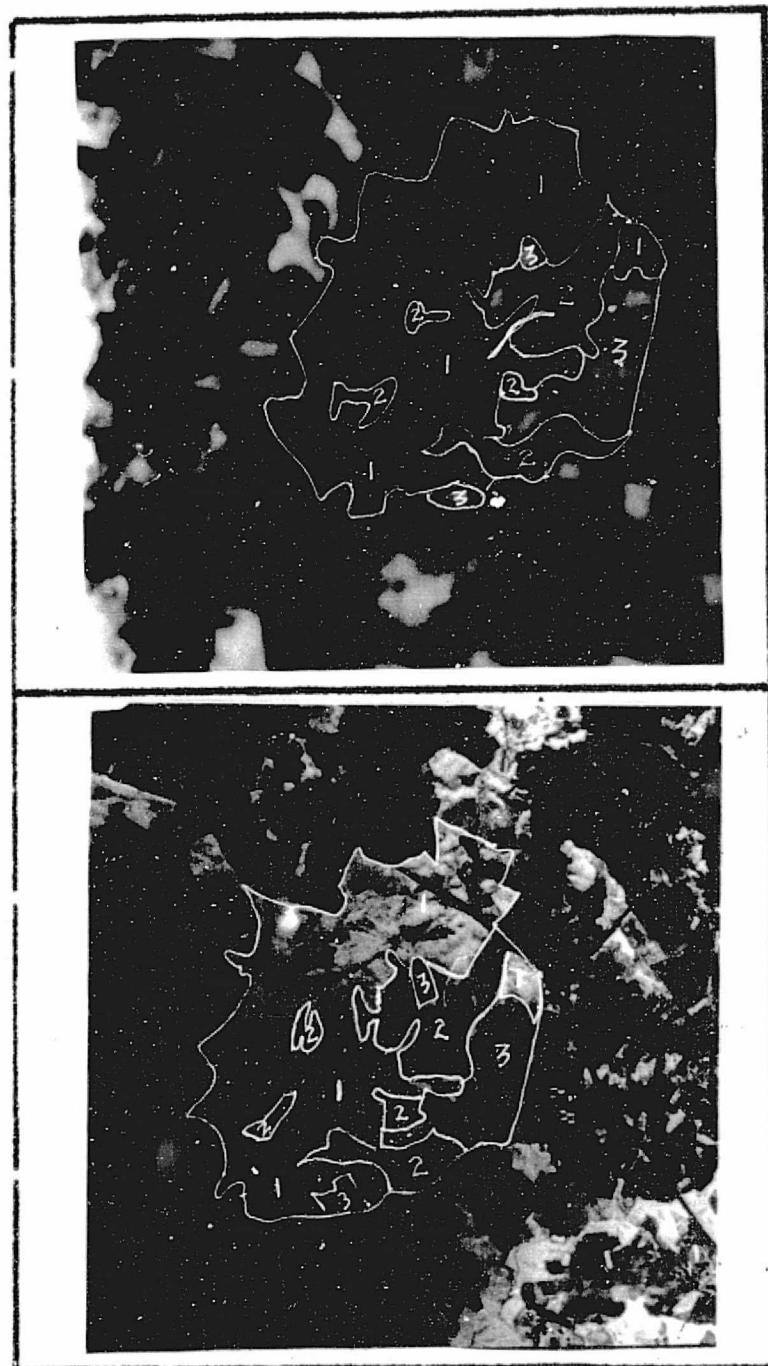
	% FORESTS n = .1	% URBAN n = .01	% FIELDS n = .03	AVERAGE "n"
AERIAL	67	12	22	.075
LANDSAT	65	11	24	.073

VI.   DEVELOPMENT OF REMOTE SENSING MODEL AND APPLICATION TO TEST
      WATERSHED

6.1   Model Development

During the course of this project, several criteria for planning
models using remote sensing were developed. They include:

1)   The model should consider all hydrologic "drivers," i.e.,
     the surface and sub-surface processes which significantly
     affect the discharge peak rate and duration.

2)   It should take maximum advantage of presently feasible
     remote sensing inputs (surface cover) and be amenable
     to new ones (soils, soil moisture, etc.) as they are
     developed.

3)   A principal function of the study should be to demonstrate
     to prospective users of LANDSAT data how remote sensing
     techniques can be applied to the general class of plan-
     ning models with actual watershed data.

A model has been deduced from standard practice and modified to a
form consistant with these criteria. It simulates the flow of rain-
water over the surface of a watershed, subjects it to subsurface abstrac-
tion (using the Holtan infiltration formula); and routes the excess
through stream channels to the outlet. Surface cover, land use, soil
type, soil moisture content, basin and channel physiography and topo-
graphy are explicitly considered.

As presently configured, the model consists of an overland flow
and a channel flow module. The overland component is based on the
conservation of rainfall volume:

$$V = qt - I$$

where:

V = overland flow volume, m^3

q = rain rate, m^3/sec,

I = total infiltration volume, m^3

t = rain duration, secs.

The volume of runoff over time is defined by the Manning relation for surface flow:

$$Q = \frac{\sqrt{s}}{n} (y)^{2/3}$$

where:

Q = surface runoff, m^3/sec

s = slope, m/m

n = Manning's surface friction coefficient

y = depth of overland flow, m

The model operates in discrete time steps, computing a depth value (y) for the beginning and end of each interval and using their average to calculate a discharge (Q). The Q values for all time steps constitute the overland flow hydrograph.

The channel flow module takes the overland hydrographs from homogeneous sub-areas of a watershed and routes them to the outlet. Manning's relationship is used to compute channel outflow. Figure 5 summarizes the model's components; a logic flow diagram and a FORTRAN listing are included in the Appendix. Table 5 lists the input data required by the model.

FIGURE 15
REPRESENTATION OF ECOSYSTEMS MODEL COMPONENTS
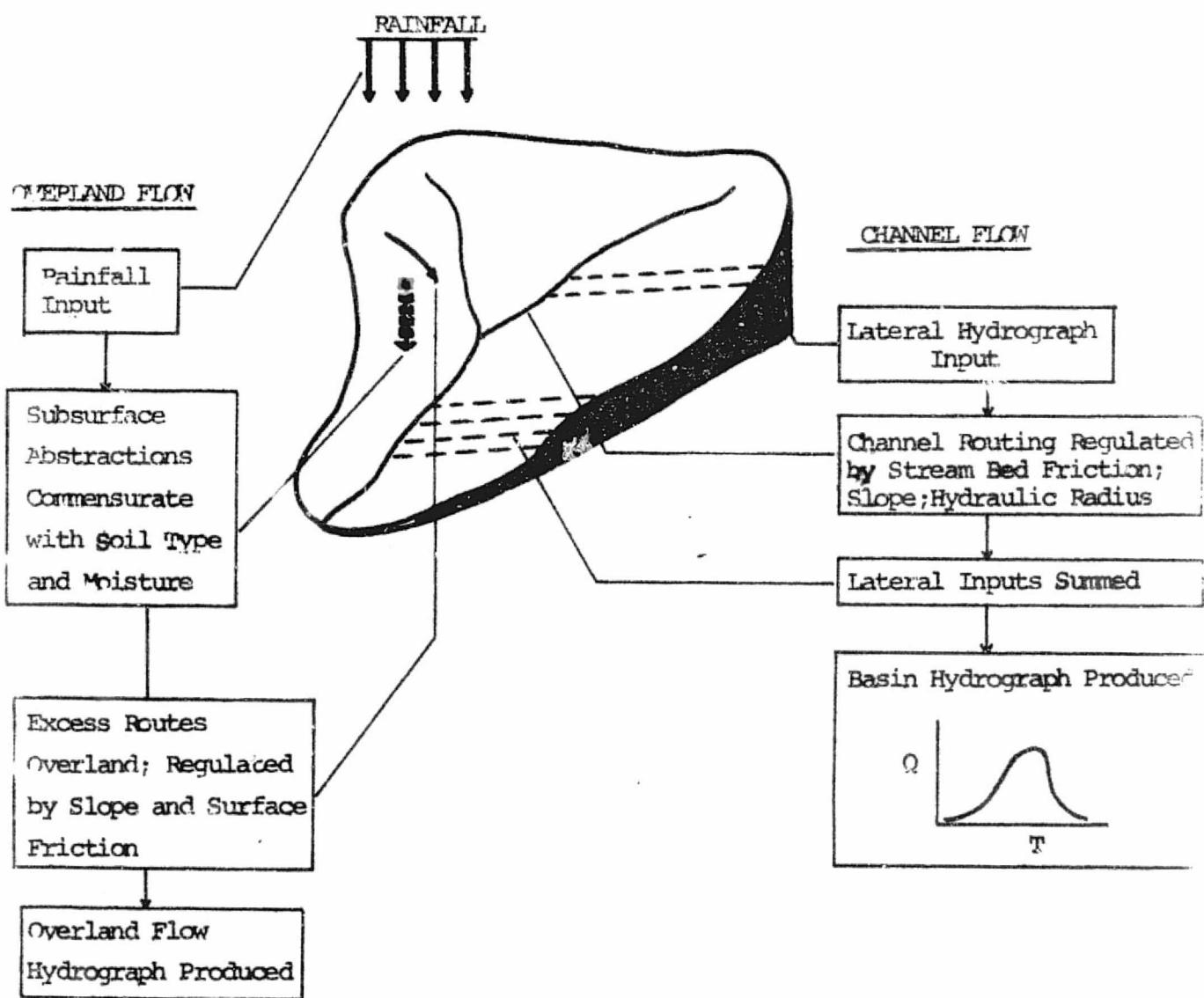
TABLE 5

SUMMARY OF ECOSYSTEMS' MODEL INPUTS

OVERLAND FLOW PARAMETERS   CHANNEL FLOW PARAMETERS

Unit strip length, meters   Channel length, meters

Unit strip slope, meters/meter   Channel slope, meters/meters

Unit strip Manning's "n"   Channel Manning's "n"

Initial depth of flow, meters   Channel Hydraulic radius, meters

SOIL PARAMETERS

Soil moisture capacity, meters/meter

Antecedent moisture content, meters/meter

Percolation rate, meters/sec.

Steady-state infiltration rate, meters/sec.

OVERLAND FLOW INPUTS   CHANNEL FLOW INPUTS

Rainfall temporal profile   Unit strip Hydrographs
       Rain rate (m/sec)   Discharge, m^3/sec
       Time (secs)   Time, secs

The parameters are input in the conversational mode, i.e., the program "asks" the modeller to enter each one as required. The output of the overland flow module is printed in tabular form and there is an option to graph the data. A sample run is shown in Figure 16.

6.2 Application of the Model to Test Watersheds

Tests were run using LANDSAT data as inputs to verify the operation of the model for typical ungaged watersheds. The tests served two purposes :

ENTER LENGTH(M), SLOPE, MANNINGS N
?0024.61.0050.0113
ENTER TIME STEP INCREMENT(SECS) AND NO. OF TIME STEPS
?010.010
ENTER TOTAL TIME LIMIT (SECS)
?001000
ENTER NUMBER OF RAIN INCREMENTS
?002
ENTER SOIL MOISTURE CAPACITY(M), ANTECEDENT MOISTURE(M), PERC(M/SEC), FINAL INFIL.(M/SEC)
?0.05030.0000.0000000000.000000
ENTER RAIN RATE(M/SEC) AND DURATION(SECS)
TOTAL RUN TIME MUST BE ACCOUNTED FOR
?.0000462050,
?.0000231050,

TIME(SECS)	RAIN(M3/SEC)	INFIL.(M3/SEC)	H(M)	FLOW(M3/SEC)	CAP.(M)
100.00	.0000462000	.0000173968	.0040939003	.0001976121	.0403938269
200.00	.0000462000	.0000165467	.0067137964	.0004514202	.0466927179
300.00	.0000462000	.0000157493	.0030688260	.0006136466	.0458742096
400.00	.0000462000	.0000150007	.0087341554	.0007004600	.0435331874
500.00	.0000462000	.0000142972	.0090823025	.0007477077	.0420649610
600.00	.0000231000	.0000136356	.0067230426	.0004524591	.0406651967
700.00	.0000231000	.0000130129	.0057176463	.0003452216	.0393298045
800.00	.0000231000	.0000124262	.0052848123	.0003026943	.0380550250
900.00	.0000231000	.0000118732	.0051271990	.0002877694	.0368373078
1000.00	.0000231000	.0000113514	.0051087737	.0002860443	.0356736705

ENTER MAXIMUM DISCHARGE - XX.XX
?00.0015
ENTER TIME SCALE STEP (SECS)
?020

SAMPLE OUTPUT OF STRIP HYDROGRAPH MODEL

FIGURE 16

-51-

TIME(SECS)   DISCHARGE(MC/SEC*12 -4)

```
        .00     1.50    3.00    4.50    6.00    7.50    9.00   10.50   12.00   13.50   15.00
    0.  I........I........I........I........I........I........I........I........I........I........I........I
   20.  I#       I        I            +       I        I        I        I       #  I        I        I
   40.  I  #     I        I            +I      I        I        I       I    #  I        I        I
   60.  I     #  I        I            +I      I        I        I        I    #  I        I        I
   80.  I      #         I        +I      I        I        I        I    #  I        I        I
  100.  I........I....#........I........+I........I........I........I........#..I........I........I........I
  120.  I        I      +  I        +  I        I        I        I        I    #  I        I        I
  140.  I        I        #        +  I        I        I        I        I    #  I        I        I
  160.  I        I        I   #    +  I        I        I        I        I   #  I        I        I
  180.  I        I        I        #  I        I        I        I        I   #  I        I        I
  200.  I........I........I........+..#........I........I........I........I....#..I........I........I........I
  220.  I        I        I        +  I #     I        I        I        I   #  I        I        I
  240.  I        I        I        +      I        I        I        I   #  I        I        I
  260.  I        I        I        ±   I        #   I        I        I   #  I        I        I
  280.  I        I        I        +  I        #   I        I        I   #  I        I        I
  300.  I........I........I........+..I........#........I........I........#..I........I........I........I
  320.  I        I        I        +  I        I +     I        I        #  I        I        I
  340.  I        I        I        +  I        I  #    I        I   #  I        I        I
  360.  I        I        I        +  I        I    +  I        I   #  I        I        I
  380.  I        I        I        ±  I        I     #  I        I   #  I        I        I
  400.  I........I........I........I..+..I........#..I........I........#..I........I........I........I
  420.  I        I        I   +    I        I        # I        I   #  I        I        I
  440.  I        I        I   +    I        I       # I        I   #  I        I        I
  460.  I        I        I   +    I        I      #I        I   #  I        I        I
  480.  I        I        I   +    I        I      #I        I   #  I        I        I
  500.  I........I........I...+....I........I........#..I........I....#..I........I........I........I
  520.  I        I        I +      I        # I    #   I        I        I        I        I
  540.  I        I        I  +     I        #+I      I        I        I        I        I
  560.  I        I        I  +     I      # # I      I        I        I        I        I
  580.  I        I        I  +     I    #   # I      I        I        I        I        I
  600.  I........I........I...+........#........#.I........I........I........I........I........I
  620.  I        I        I +      #  I      # I      I        I        I        I        I
  640.  I        I        I +    #    I      # I      I        I        I        I        I
  660.  I        I        I +  #      I      # I      I        I        I        I        I
  680.  I        I        I + +      I      # I      I        I        I        I        I
  700.  I........I........I.+.#........I........#.I........I........I........I........I........I
  720.  I        I        I++#       I      # I      I        I        I        I        I
  740.  I        I        I++       I      # I      I        I        I        I        I
  760.  I        I        I#        I      # I      I        I        I        I        I
  780.  I        I        I#        I      # I      I        I        I        I        I
  800.  I........I........I...#........I........#.I........I........I........I........I........I
  820.  I        I        #        I      # I      I        I        I        I        I
  840.  I        I        #        I      # I      I        I        I        I        I
  860.  I        I        #+       I      # I      I        I        I        I        I
  880.  I        I        #+       I      # I      I        I        I        I        I
  900.  I........I........#........I........#.I........I........I........I........I........I
  920.  I        I        #I       I      # I      I        I        I        I        I
  940.  I        I        #I       I      # I      I        I        I        I        I
  960.  I        I        +I       I      # I      I        I        I        I        I
  980.  I        I        #I       I      # I      I        I        I        I        I
 1000.  I........I........#.#........I........#.I........I........I........I........I........I
```

FIGURE 16 (cont'd)

1. To substantiate that the model is capable of producing sat-
   isfactory results as compared to similar models of ungaged
   watersheds. The watershed used was gaged and these records
   were used for comparison.

2. To demonstrate for prospective users of LANDSAT data that the
   analysis techniques described in Section IV are applicable
   in "hands-on" hydrologic modeling and provide sufficient im-
   provement to warrant their use.

The simulation test encompasses two phases: data collection and
reduction, and the actual model runs.

6.2.1 Data Collection and Reduction

The first step of this phase was the selection of a test watershed.
After study, the Bucklodge Branch basin, in Montgomery County, Maryland,
was selected. The advantages of this site were:

1. Sufficient rainfall and streamflow records were available to
   validate the model's results.

2. The watershed contains several distinct land uses providing a
   good test of what can be distinguished from LANDSAT.

3. Aerial photography ground truth existed to validate the re-
   sults of LANDSAT analysis.

4. The proximity of Bucklodge Branch permitted any moot points
   to be resolved by field survey.

Bucklodge Branch drains approximately twenty three square kilometers (9 square miles) of an urban/rural setting in Montgomery County, Maryland. The overall stream length is 32 kilometers (20 miles). The predominant land uses are rural and agricultural, including fields, forests, bare soil, surface water, and a small urbanized area. These land uses are typical of those of ungaged watershed where satellite analysis will have the most value. Bucklodge Branch is monitored by the Montgomery County Department of Environmental Protection and is equipped with two raingages and a river stage recorder. Figure 17 is a map of Bucklodge, showing the locations of the gaging sites.

The table contained in Section 6.1 listed the data which were required before the model could be run. Since the purpose of this project was to rely minimally upon non-satellite data, only data sources readily and widely available were called upon. The soils parameters, infiltration and percolation rates, were taken directly from the Soil Conservation Service survey of Montgomery County. Figure 18 exemplifies the available soils data. Slopes and lengths were measured from a U.S. Geological Survey 1:24,000 scale topographic map. Land cover data was derived solely from LANDSAT imagery. The resulting classification was verified by comparison with 1:130,000 color infrared aerial photography.

The LANDSAT imagery selected for evaluation was dated 6 October 1973. It was chosen for image quality and temporal proximity to the aerial photographs (December 1973). Multi-spectral sensor bands 4 (0.5-0.6 μm), 5 (0.6-0.7 μm) and 7 (0.8-1.1 μm) were combined in a three-band diazo

FIGURE 17

BUCKLODGE BRANCH
WATERSHED

SLIDELL ROAD
SITE

#20090
SITE

● STREAMGAGE
⊗ RAINGAGE
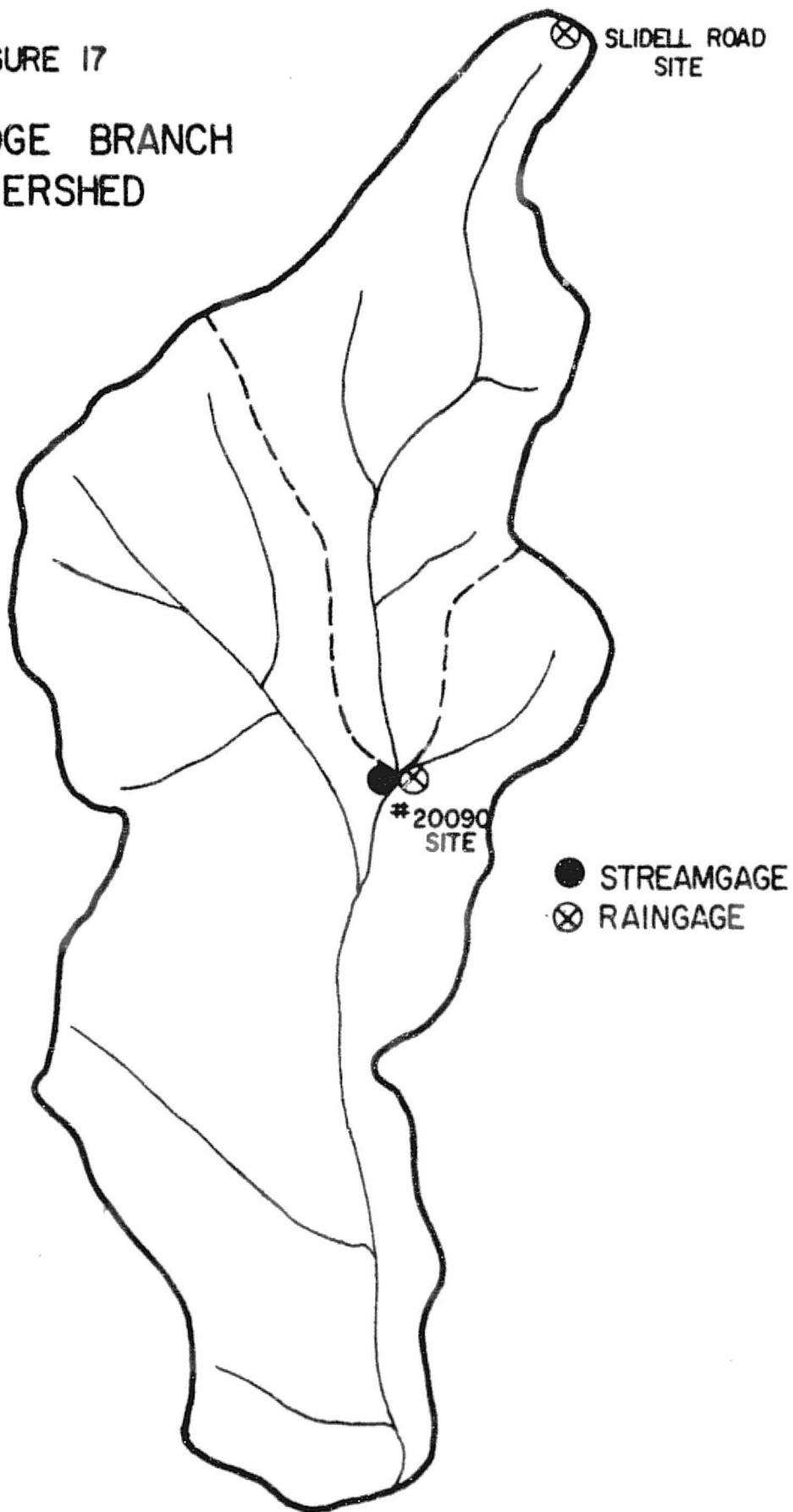
FIGURE 18

EXERPT FROM S.C.S. SOIL SURVEY OF MONTGOMERY CO., MD.

Map symbol	Soil	Depth to seasonally high water table	Depth to bedrock	Brief description of site and soil	Depth from surface (typical profile)	USDA (textural class)
		Feet	*Feet*		*Inches*	
GmA	Glenville silt loam, 0 to 3 percent slopes.	[1] 1 to 3	4+	Moderately well drained soils in draws and depressions and upland flats; developed in residuum weathered from crystalline rocks; some colluvial surface material. Seepage spots fairly common. Fragipan in subsoil.	0 to 5	Silt loam___
GmB	Glenville silt loam, 3 to 8 percent slopes.	[1] 1 to 3	4+		5 to 28	Silt loam___
GmB2	Glenville silt loam, 3 to 8 percent slopes, moderately eroded.	[1] 1 to 3	4+		28 to 42+	Silt loam___
Gr	Gullied land, Penn materials.___	[2]	0 to 2	Very severely eroded areas that originally were Penn silt loam or undetermined soils of the Penn series; very shallow; in many places bedrock is exposed.	0 to 10	Channery silt loam.
					10+	_____
HaA	Huntington silt loam, 0 to 3 percent slopes.	3	[2]	Well-drained, deep soils on flood plains; developed in alluvium derived from limestone. Infrequently flooded.	0 to 12	Silt loam___
HaB2	Huntington silt loam, 3 to 8 percent slopes, moderately eroded	3	[2]		12 to 60+	Silt loam___

| Engineering classification		Percentage passing—			Selected characteristics significant in engineering				
Unified	AASHO	No. 200 sieve	No. 10 sieve	No. 4 sieve	Range in permeability	Structure	Reaction	Dispersion	Shrink-swell potential
					Inches per hour		*pH*		
ML_____	A-4_____	65	90	95	0.63 to 2.0	Granular to subangular blocky.	4.5 to 5.5	Moderate___	Low.
ML or CL__	A-4 or A-6_	70	95	98	.06 to 2.0	Platy and subangular blocky.	4.5 to 5.0	High_____	Low.
MH_____	A-5_____	65	85	90	.20 to 0.63	Subangular blocky_____	4.5 to 5.0	High_____	Low.
ML or GM_	A-2 or A-4_	35	50	60	.20 to 2.0	Subangular blocky_____	4.5 to 5.0	High_____	Low.
GM or GC__	A-2_____	15	20	30	_____	(Fractured shale)_____	_____	_____	_____
ML_____	A-4_____	80	100	100	.63 to 2.0	Granular to platy_____	6.1 to 6.5	Moderate___	Low.
ML or CL__	A-4 or A-6_	90	100	100	.20 to 0.63	Blocky and subangular blocky.	6.1 to 7.4	Moderate___	Low to moderate

composite as described in Section 4. The color coding initially se-

lected was the same as that used by the Earth Resources Observation

Systems Data Center, i.e., Band 4 positive - yellow, Band 5 positive -

magenta, and Band 7 positive - cyan. Figure 19 is an enlargement of

the composite.

The analysis proceeded by transferring the area of the 9" X 9"

diazo containing Bucklodge Branch onto color slide film. A 35mm camera

with a slide copying attachment was used; this guarantees the color-

fastness of the image to be analyzed. The slide was projected using

the Mark I ECOsystems Universal Image Analyzer at a 1:24,000 scale.

(41.7 X magnification).

The specific steps required to translate the colors to specific

land use and cover classes were described in Section V and are sum-

marized in the following:

Step 1: Location of Watershed: The ridge line of the Bucklodge

Branch watershed was first demarked on the U.S.G.S. topographic

map. This outline defined the area to be classified. The ECO-

systems analyzer permits magnification of a projected image to

predetermined scale. By adjusting the projection distance, the

LANDSAT composite was enlarged to match the topo-map scale. The

image is reflected off an overhead mirror and superimposed on

the base map. An exact superposition is attained by adjusting

the zoom lens until alignment is achieved between lakes, roads

and/or other prominent unambiguous features in the scene. The

watershed is thus bounded by the ridge line drawn on the map.

FIGURE 19: LANDSAT DIAZO COMPOSITE, BUCKLODGE BRANCH
WATERSHED, 6 October 1973
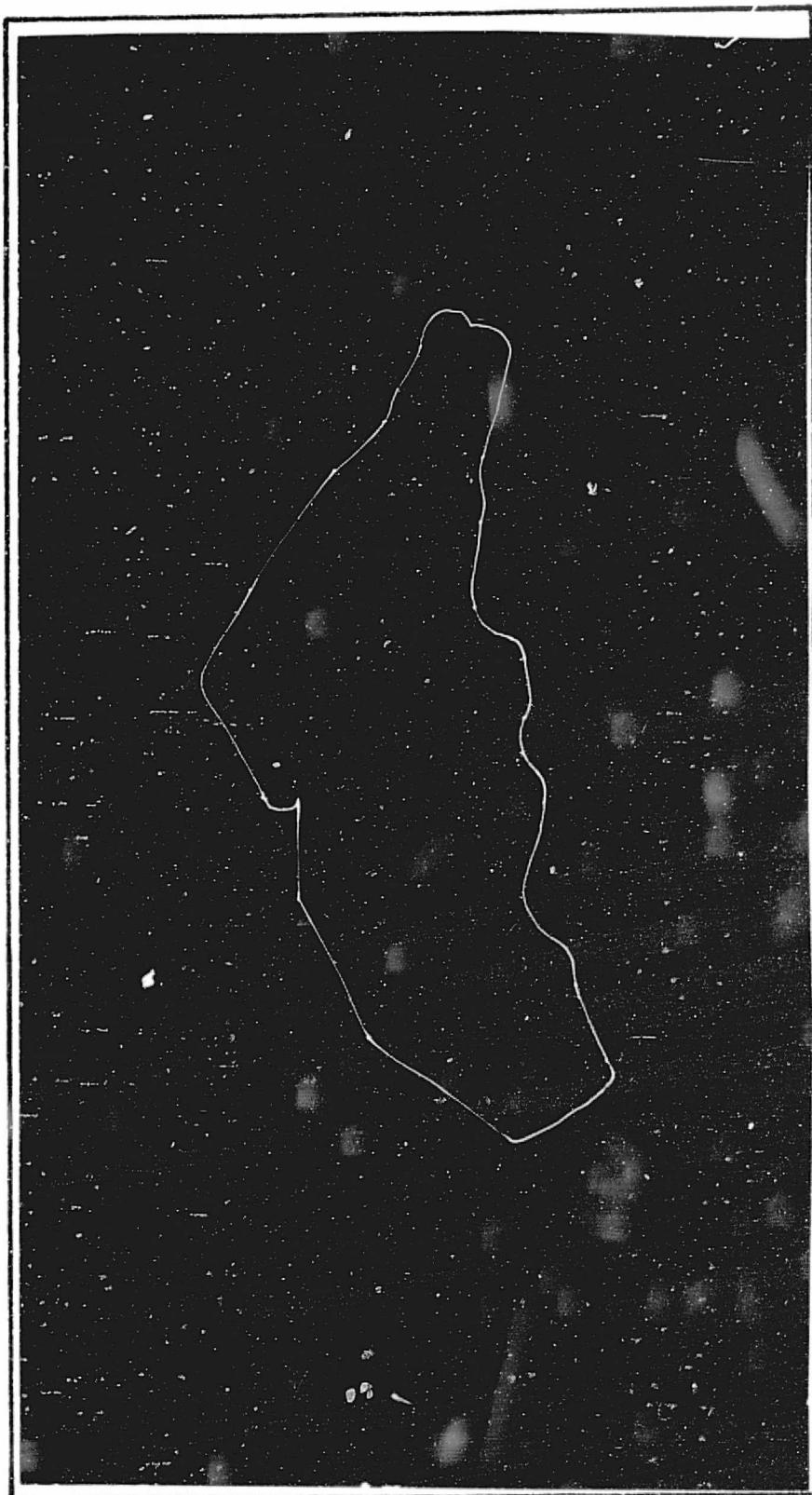
A sheet of plain paper was placed over the topo map and the basin boundary traced on it. The map was no longer needed and was removed.

Step 2: Preliminary Land Use Classification: An initial assessment of how many separable themes exist within the basin was made by visual interpretation. "Themes" in this sense actually refers to a color in the LANDSAT composite. The interpreter determined how many separable colors could be identified by reference to a set of standard color chips as indicated in Section V.

Step 3: Analysis of Ground Truth: Aerial photographic ground truth was used to test classification accuracy of the LANDSAT imagery. It was prepared in color slide format and projected, in fashion similar to the satellite composite, to a scale of 1:24,000. The watershed ridge line was marked off. In this case, however, the interpreter identified individual land use classes rather than color. The resolution of the aerial photography was sufficient to permit separation to Levels 1-2 which is adequate detail for most modeling applications. Five classes were separated – forests, fields, agricultural (fallow), surface water, and urban areas.

Step 4: Correlation of Composite Color and Land Use Class: Examination of selected test areas in the LANDSAT image with corresponding points on the ground truth photograph yielded a correlation matrix of color and land use:

COLOR	LAND USE
Black	Surface water
Blue/White	Agricultural (Fallow)
Light Red	Fields
Dark Red	Forests
Red/Blue	Urban

Step 5: <u>Analysis of Classification Results</u>: The area of each class was measured with a calibrated grid overlay. The results are summarized in Table 6.

TABLE 6

SUMMARY OF CLASSIFICATION RESULTS

CLASS	AREA, LANDSAT IMAGE (ha)	AREA, AERIAL PHOTO (ha)	RELATIVE ERROR
Fields	1,479	1,510	-2%
Forests	767	738	+4%
Urban	10	9	+11%
Surface Water	7	8	-17%
Agricultural (Fallow)	87	85	+2%
TOTAL	2,350	2,350	2,7%

The classification results indicate a high overall accuracy. It was observed that large (greater than 10%) relative errors resulted only from classes with very small absolute areas (less than 1% of total watershed area). In the case of urban areas, for example, the 9 hectare total area was distributed over six separate sites, none larger than about three hectares. The total surface water area of 8 hec-

tares was divided among nine individual lakes. Figure 20 indicates that
the relative error is a monotonically decreasing function of area of
the class, as supported by theory. All points fall close to the theo-
retical line with the exception of agricultural (fallow) areas, which
displayed an error less than that expected. This further indicates
that, because of the radiometric characteristics of agriculture lands,
October is a good time to "look" for these, i.e., their contrast with
surrounding areas is particularly high. This demonstrates the value
of multi-temporal imagery indicated in Section V.

6.2.2 Peak Event Modeling of Bucklodge Branch

A simulation for all of Bucklodge Branch was not attempted since
the stream gage is not located at the outlet. Bucklodge Branch was
modeled down to the gage point in order that the results could be veri-
fied. Figure 21 is a reproduction of the U.S.G.S. 1:24,000 scale topo-
graphic map of this section. The heavy lines delineate important sub-
basins. The data collected earlier indicated that there were no dra-
matic variations in soils, topography, flow length, or surface cover
within any subbasin.

The model used approximates the natural basin subareas with rec-
tangular strips possessing averaged surface and subsurface character-
istics. For Bucklodge Branch, each subbasin was replaced by two strips
representing the areas on either side of the main channel as shown in
Figure 22. The area of each strip was set equal to that of the subarea
it represents. Its length is assumed equal to the channel length.
This fixes the width, which is indicative of the overland flow length.

FIGURE 20

LANDSAT vs. AERIAL INVENTORY ERROR – BUCKLODGE BRANCH

| CLASS	% ABS ERROR
Forest	4
Fields	2
Agricultural (Fallow)	2
Urban	11
Water	13
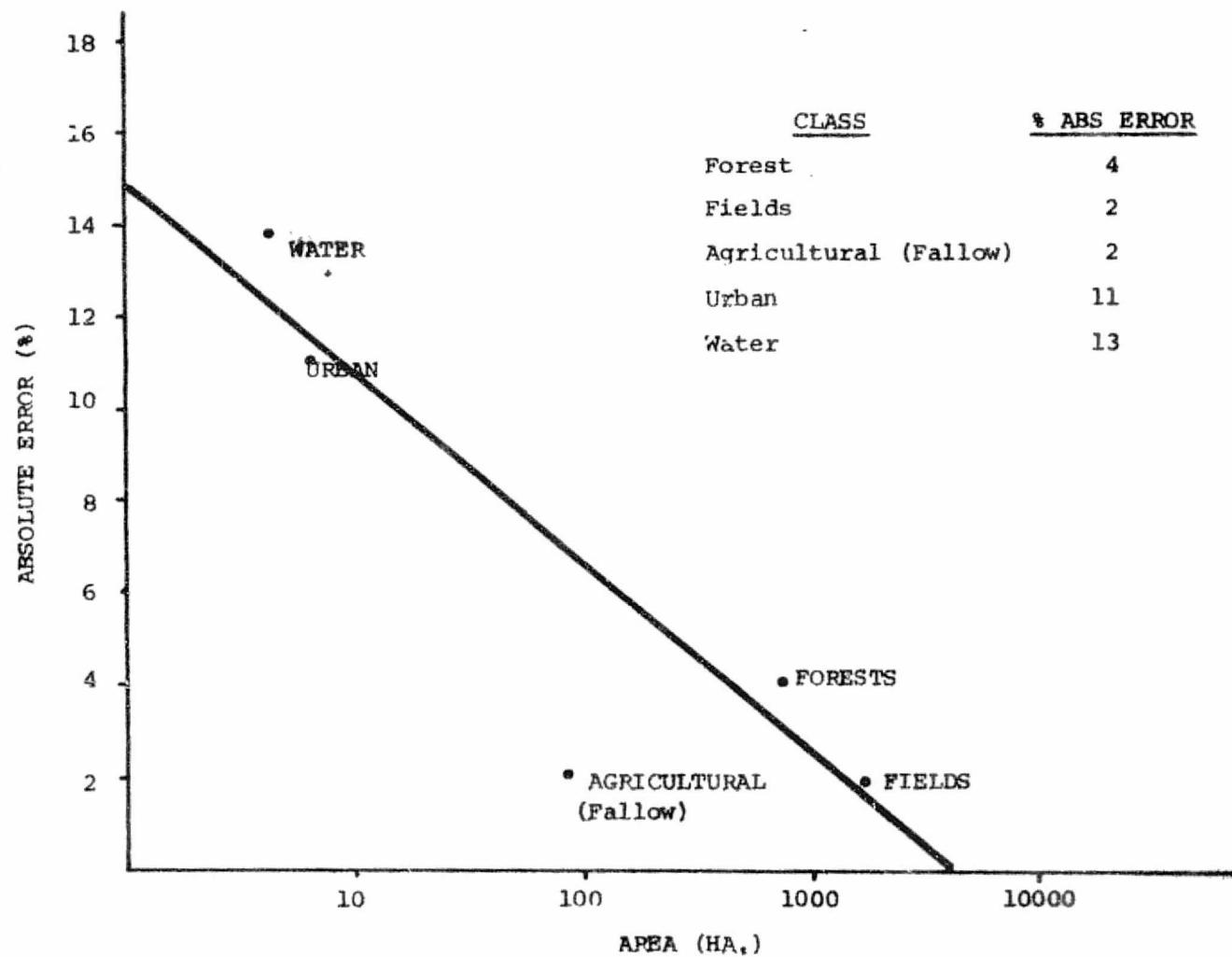
FIGURE 21 BUCKLODGE BRANCH
MAJOR SUBBASINS
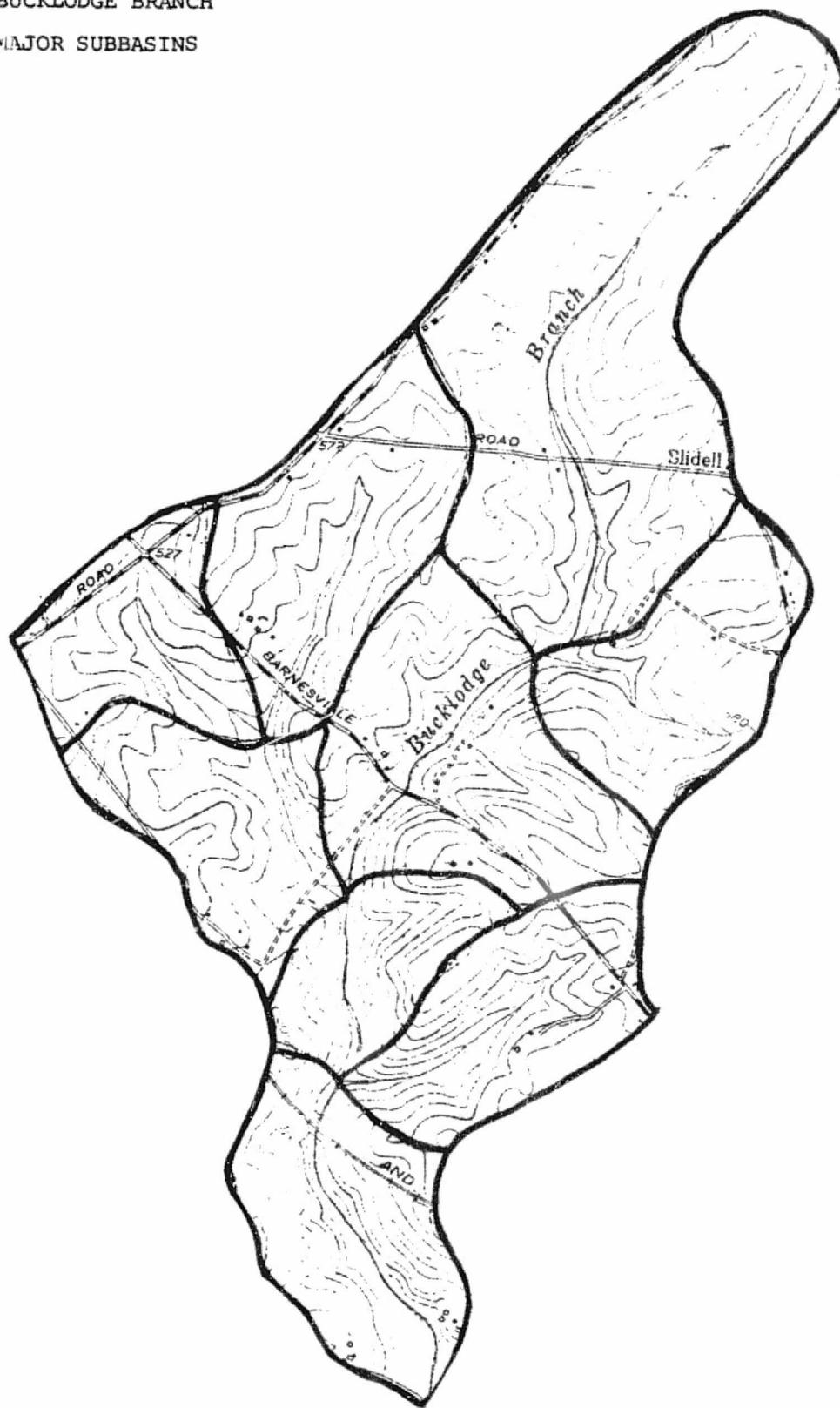
FIGURE 22

BUCKLODGE BRANCH - UNIT STRIPS
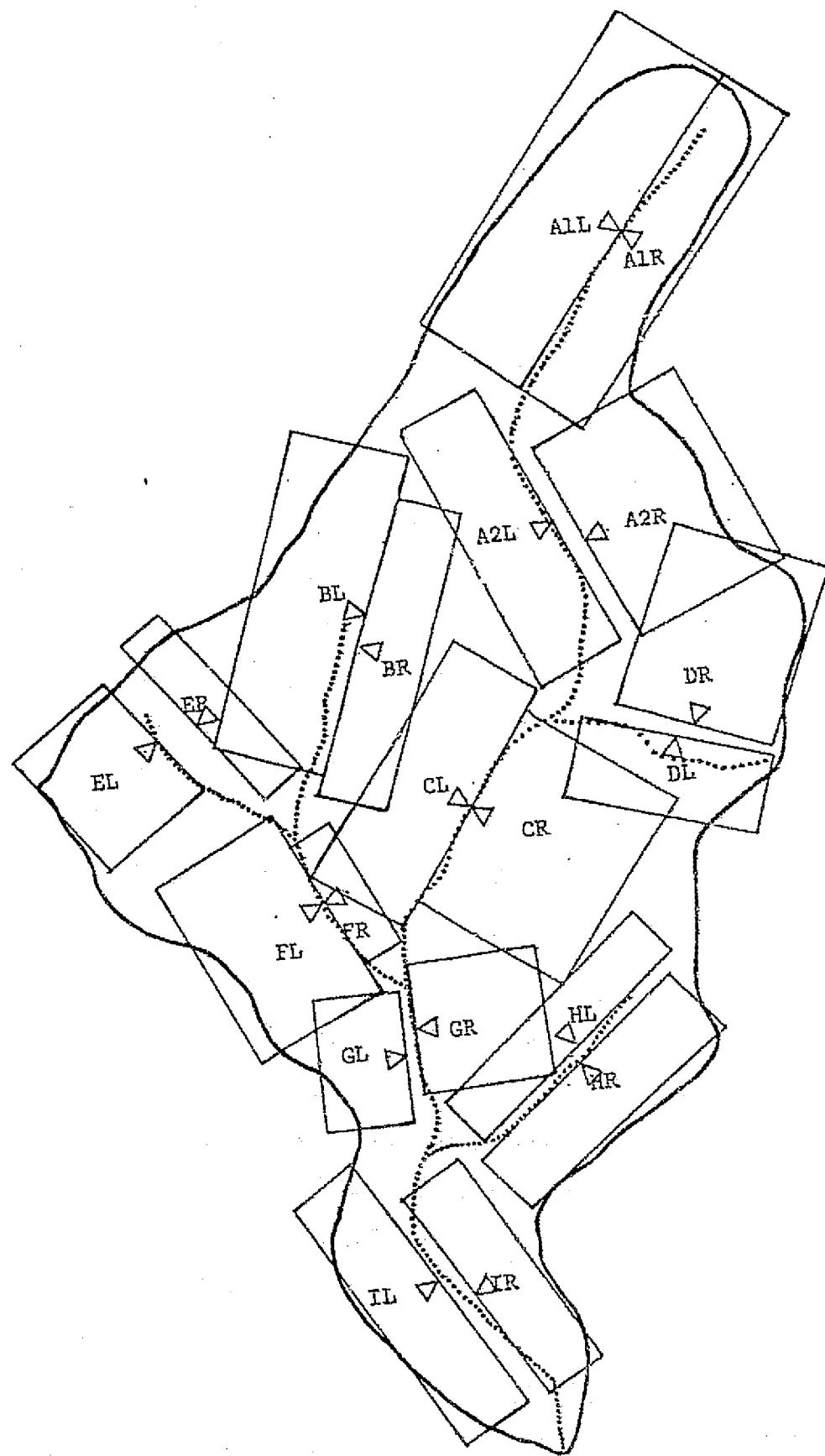
Slopes and soil parameters are averaged over the area of the strip. Table 7 summarizes the parameter assignment for each strip.

Figure 23 presents the hydrologic schematic for the surrogate watershed. The modelling process now requires that rainfall from a test event be input to each strip and the resultant runoffs routed down the channels. Characteristic rainfall test event were selected from among records obtained from the two rain gages in the watershed. The rain and resultant runoff stage readings are reproduced in Figure 24. Rainfall inputs applied to each strip were taken as a weighted average of the two raingages.

Model runs for the particular rain event selected showed that no overland flow was produced by thirteen of the twenty strips. Overland flow from the remaining seven were input to the routing module and the outflow hydrograph was derived. Preliminary runs indicate that overall basin response is heavily dependent upon the initial soil moisture condition assumed; a reasonable level of initial soil moisture was set, therefore, based on the analysis of rainfall for 14 days prior to the event. It should be noted that sensitivity to antecedent moisture is an important common characteristic of planning models; it may be a source of additional benefits from remote sensing of soil moisture in the future.

Results of the overland and routing runs are shown in Figure 25. The model exhibited a good approximation of actual discharge as computed from the gage records and rating curve. The results to date are encouraging. Even more important from the standpoint of modeling,

FIGURE 23

HYDROLOGIC SCHEMATIC - BUCKLODGE BRANCH
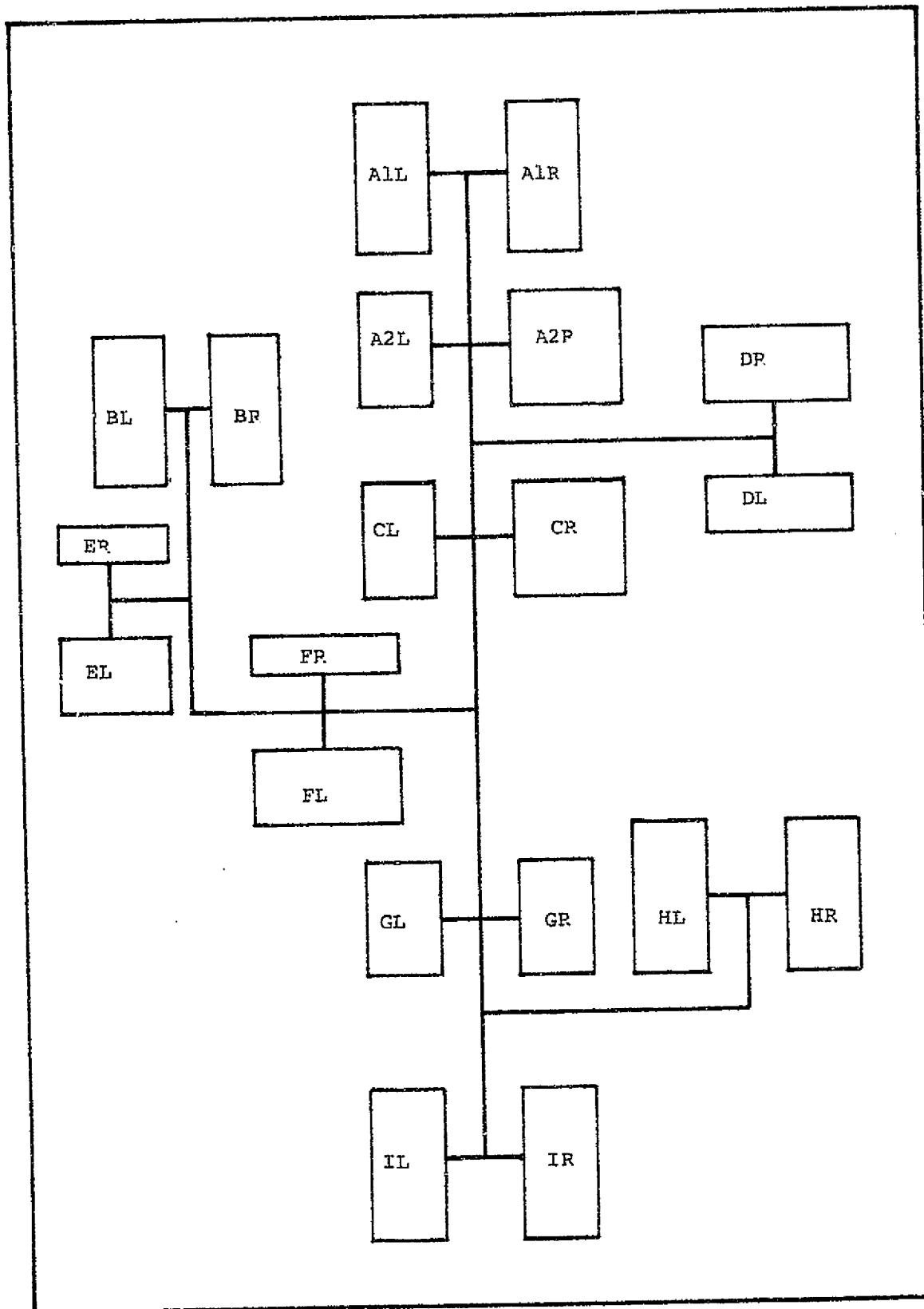
TABLE 7

BUCKLODGE — HYDROLOGIC DATA OF COMPONENT STRIPS

No.	STRIP	LENGTH (M)	WIDTH (M)	AREA (M²)	SLOPE	MANNING's N	MOISTURE CAPACITY (M)	PERC. (M/SEC)	FINAL INFILTRATION (M/SEC)
1	AIL	402.34	1626	6504.00	.040	.076	.038	.00000134	.000004445
2	AIR	271.27	1192	323353.84	.060	.076	.036	.00000119	.000004445
3	AR	463.29	1051	486917.79	.060	.044	.037	.00000105	.000004445
4	AZL	509.02	847	431292.40	.060	.031	.039	.000001129	.000004445
5	BL	505.97	852	431086.4	.070	.045	.063	.000001917	.000004445
6	BR	298.70	1207	360530.90	.080	.045	.036	.00000105	.000004445
7	CL	384.05	1045	401332.25	.080	.045	.035	.00000184	.000004445
8	CR	408.43	1237	505227.90	.080	.057	.038	.000001129	.000004445
9	DL	542.54	719	390086.26	.050	.056	.039	.00000127	.000004445
10	DR	304.80	793	241706.4	.060	.037	.060	.000001199	.000004445
11	EL	353.57	841	297661.70	.060	.055	.056	.000001129	.000004445
12	ER	323.09	518	167360.62	.060	.062	.066	.000001341	.000004445
13	FL	548.64	955	523951.2	.060	.044	.052	.000001199	.000004445
14	FR	201.70	443	89353.10	.090	.045	.030	.000000847	.000004445
15	GL	262.13	425	111405.25	.130	.084	.070	.0000014110	.000004445
16	GR	457.20	528	241401.60	.120	.081	.065	.00000134	.000004445
17	HL	286.51	986	282498.86	.110	.084	.066	.00000134	.000004445
18	HR	310.90	1100	341990.00	.070	.086	.048	.00000119	.000004445
19	IL	329.18	1230	404891.4	.110	.075	.066	.00000134	.000004445
20	IR	280.42	967	271166.14	.110	.097	.047	.00000134	.000004445

FIGURE 24: BUCKLODGE BRANCH WATERSHED PRECIPITATION AND DISCHARGE GAGE RECORDS EVENT OF 15-17 JUNE 1976
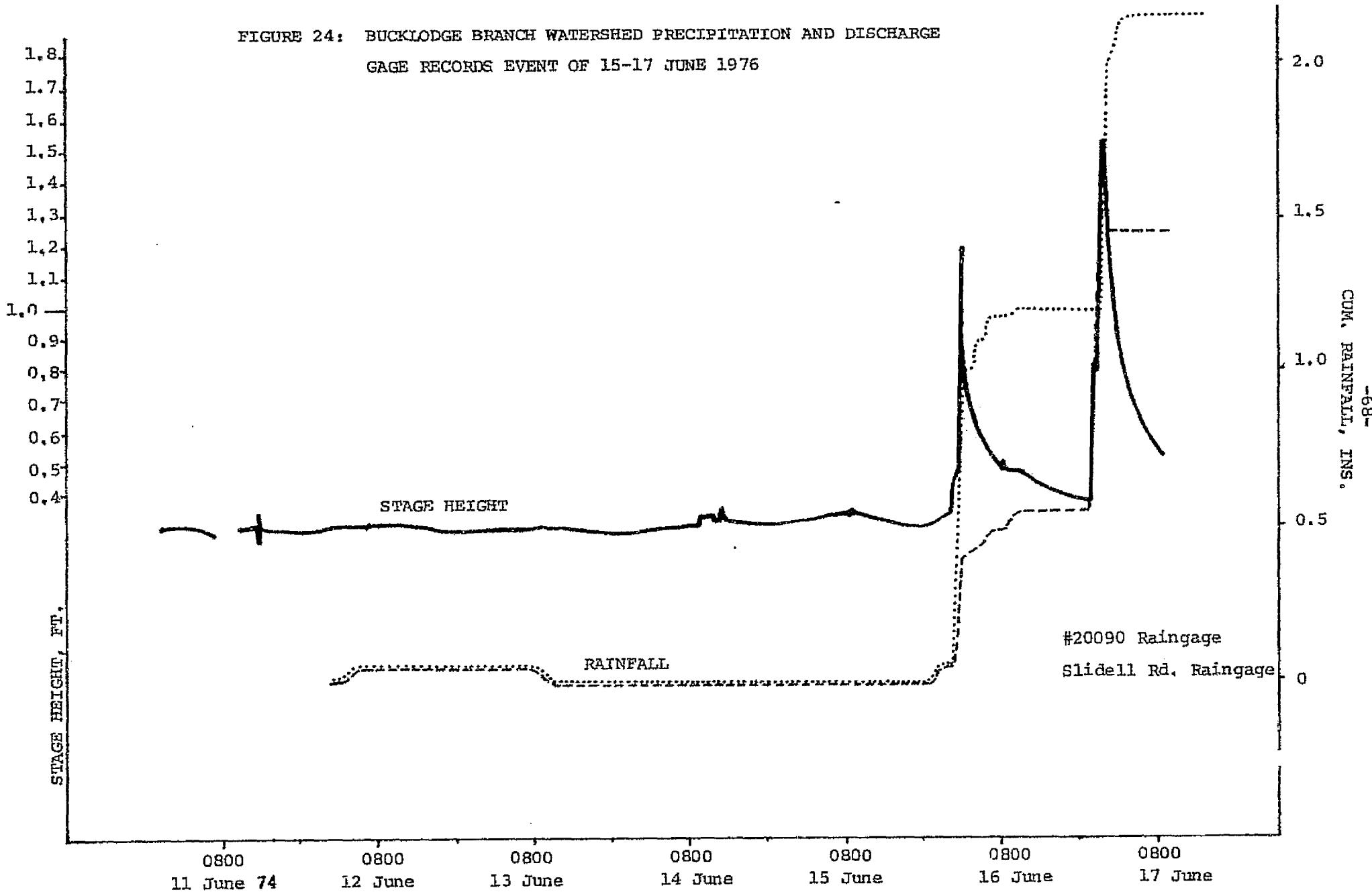
FIGURE 25

RAINFALL/RUNOFF EVENT OF 12 - 17 JUNE 1974

BUCKLODGE BRANCH WATERSHED
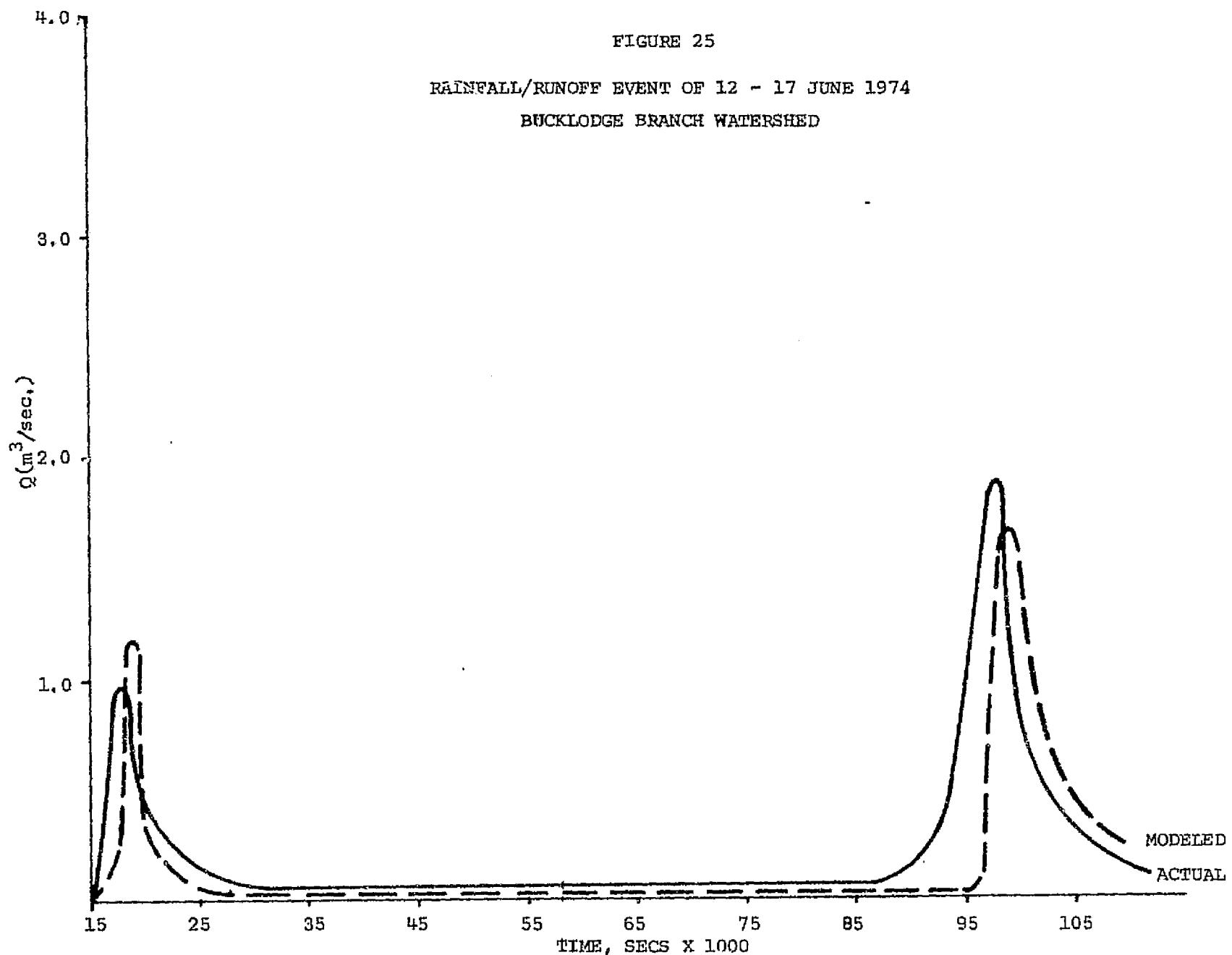
however, is that the analysis techniques developed have been success-
fully related to actual hydrologic situations. This applicability
extends beyond the model developed in this effort, and should prove
valuable to a large class of modelers and users within the hydrologic
community.

6.3 Implications of the Introduction of Remote Sensing Data into
Hydrologic Planning Model

1. Satellite remote sensing can yield assessments of hydrologic
   land use sufficient for modeling purposes. The radiometric
   and multitemporal properties of the imagery can facilitate
   classification and provide new and additional information
   with respect to seasonal and developmental changes.

2. This information will be of value to a large section of hy-
   drologic applications.

3. The assessment of soils and soil moisture conditions is pre-
   sently difficult for modellers due to its temporal variabil-
   ity and the lack of records. Future inputs from remote sen-
   sing in this area would be most valuable.

4. The techniques derived and the demonstration made herein
   should function as a guide for the application of LANDSAT
   data by hydrologic modellers to their models on basins of
   concern to them.

VII. TECHNOLOGY TRANSFER TO THE USER COMMUNITY

The preceding analysis has indicated the applicability of remote sensing from LANDSAT to hydrology by confirming its adequacy as a source of surface cover information. The remaining problem was how best to introduce these results to users. Though hydrologists are generally familiar with conventional (aerial) remote sensing, the satellite data stream has not as yet seen wide use. This section will describe the problems involved in the technological transfer and the results achieved to date, and will present recommendations for future efforts.

7.1 Description of the User Community

Results from a previous NASA-GSFC/ECOsystems effort, synthesized following, characterized the hydrologic model users:

1. In the United States, agencies and organizations concerned with water resources number in excess of 6,000.

2. The principal contributor to research, development and implementation of water-resource models is the federal Government, with over 80% of the budget. Most of the federal effort is carried on by 11 federal agencies and their contractors.

3. In descending order of activity are state agencies (several hundreds), state water resources institutes (50), universities (70 principal), local governments (in excess of 3,000), and private contractors (approximately 3,000).

4. State water resource institutes and universities are primarily funded by the federal government. Most private contractors primarily support local Governments.

5. The eleven federal agencies which primarily "drive" hydrologic efforts are:

   Department of Commerce - National Oceanographic & Atmospheric Administration

   Department of Agriculture

   a. Agricultural Research Service

   b. Soil Conservation Service

   c. Forest Service

   Department of the Interior

   a. Geological Survey

   b. Bureau of Reclamation

   c. Fish and Wildlife Service

   d. Bonneville Power Administration

   Environmental Protection Agency

   Department of Defense - Army Corps of Engineers

   Tennessee Valley Authority

6. The hydrologic community is diverse in its membership and in the models they use. There exists, therefore, no single focus at which satellite data analysis can be integrated into standard practice.

7. The diversity of users has recently been expanded with the
    emergence of several federal water resources planning pro-
    grams which tend to move some of the activity away from
    federal groups and toward local and regional agencies.
    This further accentuates the need for using simple analysis
    procedures and hardware that can be employed within the con-
    straints of local government budgets.

7.2 Impediments to Expanded Use of Remote Sensing in Hydrology and
     Suggestions for Overcoming Them

In addition to the diffuse make-up of the user community, two other
problems are experienced in amplifying the use of LANDSAT data. There
exists in any research activity a natural applications delay between in-
vention and acceptance. New procedures must compete with everyday prac-
tice and must overcome an understandable inertia. In the case of
LANDSAT data there exists a certain skepticism not dissimilar to the one
encountered by any innovation. It is increased by the limitation of re-
sources available to any one user, which makes him naturally hesitant to
attempt new techniques without a certainty of their results. Such skep-
ticism is healthy, however, and forces that the claims made for LANDSAT
be thoroughly tested and made relevant to the user.

A recommended strategy for exposure of the new procedure, therefore,
is not to represent LANDSAT as a panacea for all problems; rather, speci-
fic applications of interest to specific users should be "benchmarked."
For this reason, this effort did engage in a specific benchmark test,
as reported in Sections V and VI of this report. The test and the pro-

cedures developed and described herein can be repeated by any small or medium user on his own watershed, and the accuracy and cost of results thereby certified for his specific application.

7.3   Summary of User Contacts Made to Date

Efforts made during this study to foster the expanded use of remote sensing for hydrologic modeling encountered the impediments described above.   Nevertheless, significant successes were also encountered with overseas users.   Principal among these were:

1.   A hydrologic modeling effort, based essentially upon the developments accomplished under NASA sponsorship, was contracted by the Region of Tuscany, Italy.

The model embraces a watershed of approximately 90,000 Hectares, with mixed urban, agricultural, forest, mountainous contents.   The model must be able to:

a)   Predict runoff events in real time for matching supply against demand.

b)   Provide flood warning

c)   Provide accurate runoff predictions for unusual events (planning model) for the sizing of waterworks.

d)   Simulate the effect of changes in land use---reforestations, industrial parks, urban expansion----upon the watershed's hydrologic regime.

The effort additionally includes complete transfer of modeling and remote sensing technology to the customer.

This effort proved that the technique of planning models developed herein could be extended to general hydrologic modeling. The Tuscany model includes quarterly updates of the ground cover of the entire watershed from LANDSAT-derived information.

2. The specification of a facility for the analysis of LANDSAT data was contracted by the same customer. This includes visual and computerized data processing, employing their on-premise 370/135 computer, and using the LANDSAT data derived from the Telespazio receiving station located near Rome, Italy. The LANDSAT data are to be used for general land-use information as well as for hydrologic modeling.

3. An image-analysis device, of the type described previously, was acquired by the University of Naples, Italy, for the analysis of land use, water pollution and the inventory of selected crops.

4. A land-use map of high precision, including hydrologic properties, was contracted by the Region of Basilicata, Italy. The techniques employed will be those developed under this effort and reported herein.

The high interest of the foreign user community is attributed to the relatively small number of agencies working in hydrologic modeling and the concentration of these activities within regional governmental users.

The domestic situation differs in that the level of the technology transfer effort required is proportional to the number of users involved. On the domestic scene, initial contacts have been made to date with U.S.G.S., Water Resources Division; USDA, Agricultural Research Service, and the Maryland Department of State Planning. As previously discussed, cultivation of interest with these and other organizations will be greatly aided by concise benchmark tests.

APPENDIX A

STRIP HYDROGRAPH MODEL

FLOWCHART AND FORTRAN LISTING

FIGURE A1

STRIP MODEL WITH SOIL MOISTURE ACCOUNTING

START

INITIALIZE SOIL MOISTURE PARAMETERS, H, Q,
SLOPE, N, LENGTH, TIME PARAMETERS

READ RAIN RATES & INTERVALS & COMPUTE
TEMPORAL PROFILE

G — INCREMENT TIME COUNTER

IF TIME = LIMIT; GO TO PLOTTING ROUTINE

SYMBOLS:

HAS WATER ACCU-
MULATED ON THE
SURFACE?

IS
H > 0?   NO   A

YES

H = Depth of Flow

R = Rain Rate

F = Infiltration Rate

S = Soil Moisture Cap.

HAS THE RAIN
STOPPED?

IS
R = 0   YES   B

NO

Dl = Computation Time
Interval

Q = Discharge

SL = Slope

N = Manning's N

I_f = Final Infiltration
rate

IS SOIL MOISTURE
CAPACITY FILLED?

IS
S = 0   YES   C

NO

COMPUTE INFILTRATION RATE = $S^{1.4} + I_f$

COMPUTE NEW DEPTH OF FLOW (H) = H + (1.6 Dl (R - Q - F)

IS NEW DEPTH
> 0

IS
H > 0   NO   H

YES

COMPUTE DISCHARGE (Q) = $\dfrac{\sqrt{SL}\, H^{1.67}}{N}$

E

FIGURE A1 (cont'd)

FIGURE A1   (cont'd)

IS SOIL
MOISTURE
CAPACITY FILLED?

B

IS
S = 0   YES   INFIL. RATE = PERC. RATE

INFIL. RATE = $S^{1.4} + I_f$

COMPUTE DEPTH (H) = (H + 1.6D (Q - F)

IS. NEW
DEPTH > 0?

IS
H > 0?   NO   **H**

YES

COMPUTE DISCHARGE (Q) = $\dfrac{\sqrt{SLH}}{N}^{1.67}$ **E**

C

INFIL. RATE = PERC. RATE
COMPUTE DEPTH (H) = (H + 1.6 D1 (R - Q - F)

IS NEW
DEPTH > 0?

IS
H > 0   NO   **H**

COMPUTE DISCHARGE (Q) = $\dfrac{\sqrt{SLH}}{N}^{1.67}$

E

E

COMPUTE MOISTURE GAINED OR LOST FOR
PRESENT TIME INTERVAL, (S DELT) =
(F-PERC) AND TOTAL CAPACITY REMAINING
(S) = CAPACITY - INITIAL MOISTURE -
Σ S DELT

IS PRINT-OUT
DESIRED AT
THIS TIME
INTERVAL?

IS
K > J   NO   **G**

YES

WRITE H, Q, F, T, S, R

G

TABLE AI

FORTRAN LISTING OF STRIP HYDROGRAPH MODEL

```
  $$LENGTH:132
          DIMENSION Q(500),R(500),S(500),F(500),XLN(100),U(25),V(25),M(25),CTR(15)
  120   10 FORMAT ('ENTER LENGTH(M), SLOPE, MANNINGS N')
  130   20 FORMAT (F7.2,2F5.4)
  140   30 FORMAT ('ENTER TIME STEP INCREMENT(SECS) AND NO. OF TIME STEPS')
  150   39 FORMAT ('ENTER TIME SCALE STEP (SECS)')
  160   40 FORMAT (F4.0,I3)
  170   45 FORMAT ('ENTER TOTAL TIME LIMIT (SECS)')
  180   46 FORMAT (I6)
  190   94 FORMAT (//////,2X,' TIME(SECS)',43X,' DISCHARGE(M3/SEC*10 -4)',
  191   95 FORMAT (/,7X,10(F5.2,5X),F5.2)
  167  205 FORMAT (5X,F9.2,5X,F15.10,5X,F15.10,5X,F15.10,5X,F15.10,5X,F15.10)
  190   50 FORMAT ('ENTER NUMBER OF RAIN INCREMENTS')
  200   60 FORMAT (I3)
  210   70 FORMAT ('ENTER RAIN RATE(M/SEC) AND DURATION(SECS)')
  220   80 FORMAT ('TOTAL RUN TIME MUST BE ACCOUNTED FOR')
  230   78 FORMAT (F8.7,F5.0)
  240   91 FORMAT (2F6.4,2F11.9)
  250   92 FORMAT (5X,'0.',3X,'I',100A1)
  255   99 FORMAT (////,30X,'+ INDICATES INFILTRATION',/,30X,'* INDICATES DISCHARGE',/,30X,'# INDICATES RAINFALL')
  260  101 FORMAT ('ENTER SOIL MOISTURE CAPACITY(M), ANTECEDENT MOISTURE(M), PERC(M/SEC), FINAL INFIL.(M/SEC)')
  270  141 FORMAT (3F9.7)
  280  151 FORMAT (//////,6X,'TIME(SECS)',7X,'RAIN(M3/SEC)',7X,'INFIL.(M3/SEC)',11X,'H(M)',13X,'FLOW(M3/SEC)',10X,'CAP.(M)')
  290      WRITE (108,10)
  300      READ (105,20) XL,SL,EN
  310      WRITE (108,30)
  320      READ (105,40) D1,J
  330      WRITE (108,45)
  340      READ (105,46) N1
  350      WRITE (108,50)
  360      READ (105,60) J1
  370      WRITE (108,101)
  380       READ (105,91) CAP,API,PERC,F3
  390      M(1)=0
  400      WRITE (108,70)
  410      WRITE (108,80)
  420      DO 102 I=1,J1
  430  102 READ (105,99) V(I),U(I)
  440      J2=J1+1
  450      DO 111 I=2,J2
  460  111 M(I)=IDINT(U(I-1)/D1)+M(I-1)
  470      DO 121 L=2,J2
  480      L1 = M(L-1) + 1
  490      L2 = M(L)
  500      DO 121 K1=L1,L2
  510  121 R(K1) = V(L-1)
  520      N1 = M(J2)
  530      N=IDINT(N1/D1)
  540      F5=(SL**.5/EN)
  550      WRITE (108,151)
  560      H=0.
  570      SDELT=0.
  580      K=0
  590      S(1) = CAP-API
  595      F3=F3*141732.
  600      DO 321 I=1,N
```

TABLE AI (cont'd)

```
610       K=K+1
630       T = D1*I
640       IF (H .LE. 0.) GO TO 251
650       IF (R(I).LE.0.) GOTO 231
670  231  IF (S(I) .LE. 0.) GO TO 271
675       S(I) = S(I)*39.37
680       F(I) = ((S(I)**1.4+F3))
690       F(I) = F(I)/141732.
695       S(I) = S(I)/39.37
700       H=H+(1.6*D1*(R(I)-(Q(I-1)/XL)-F(I)))
710       IF (H .LE. 0.) GO TO 281
720  241  Q(I) = F5*.307*H**1.67
730       GO TO 291
740  251  IF (R(I) .LE. 0.) GO TO 255
750       IF (S(I) .LE. 0.) GO TO 257
760       S(I) =S(I)*39.37
770       F(I) = ((S'I)**1.4+F3))
775       S(I) = S(I)/39.37
780       F(I) = F(I)/141732.
790       IF (F(I) .GT. R(I)) F(I) = R(I)
800       H=1.6*D1*(R(I)-F(I))
810  253  IF (H .LE. 0.) GO TO 281
820       Q(I) = F5*.307*H**1.67
830       GO TO 291
840  255  F(I) =0.
850       H=0.
860       Q(I) =0.
870       GO TO 291
880  257  S(I) =0.
885       F(I) = PERC
890       IF (F(I) .GT. R(I)) F(I) = R(I)
900       H=1.6*D1*(R(I)-F(I))
910       GO TO 253
920  271  S(I) =0.
925       F(I) = PERC
930       H=H+(1.6*D1*(R(I)-(Q(I-1)/XL)-F(I)))
940       GO TO 253
950  281  H=0.
960       Q(I) =0.
970  291  SDELT = (F(I)-PERC)*D1
972       IF (SDELT .LT. (S(I)-CAP)) SDELT = S(I)-CAP
975       S(I+1)=S(I)-SDELT
976       IF (S(I+1).LT.0.) S(I+1)=0.
977       IF (S(I+1).GT.CAP) S(I+1)=CAP
980       IF (K .LT. J) GO TO 321
990       WRITE (108,205) T,R(I),F(I),H,Q(I),S(I)
1010      K=0
1020 321  CONTINUE
1030      DATA STAR,BLANK,DOT,S_SH,PLUS,PND/'*',' ','.','/','I','+','#'/
1040 37   FORMAT (2X,F5.0,3X,A1,100A1)
1050      WRITE (108,36)
1060 36   FORMAT (///////,'ENTER MAXIMUM DISCHARGE - XX.XX')
1070      READ (105,38) Q
1080 38   FORMAT (F12.10)
1090      WRITE (108,39)
1100      READ (105,60) I2
1110      IX = I2/D1
1120      WRITE (108,99)
1130      WRITE (108,94)
```

TABLE AI (cont'd)

```
1140      H1=D/100.
1150      LN=0
1160      CTR(1) = 0.
1200      TIME =0.
1210      D2=H1*10.
1220      DO 301 I=1,10
1230  301 CTR(I+1) = I*D2
1232      WRITE (108,95) (CTR(I),I=1,11)
1235      DO 308 J=1,100
1237  308 XLN(J) = DOT
1250      DO 309 I=10,100,10
1260  309 XLN(I) = SLSH
1270      WRITE (108,92) XLN
1290      DO 501 I=IX,N,IX
1290      TIME = TIME+I2
1295      F(I) = F(I)*XL
1298      R(I) = R(I)*XL
1299      G=SLSH
1300      J6=IDINT((F(I)*10000)/H1+.5)
1301      IF (J6 .EQ. 0) G=PLUS
1304      J5 = IDINT((R(I)*10000.)/H1 + .5)
1305      IF (J5 .EQ. 0) G=PND
1308      J8 = IDINT((Q(I)*10000.)/H1 +.5)
1309      IF (J8 .EQ. 0) G=STAR
1310      LN=LN+1
1320      IF (LN .EQ. 5) GO TO 315
1330      DO 103 JK=1,100
1340  103 XLN(JK) = BLANK
1350  104 DO 105 JK=10,100,10
1360  105 XLN(JK) = SLSH
1363      IF (J6 .EQ. 0) GO TO 504
1365      XLN(J6) = PLUS
1380  504 IF (J5 .EQ. 0) GO TO 508
1385      XLN(J5) = PND
1386  508 IF (J8 .EQ. 0) GO TO 510
1387      XLN(J8) = STAR
1390  510 WRITE (108,37) TIME,G,XLN
1400      GO TO 501
1410  315 DO 109 JK=1,100
1420  109 XLN(JK) = DOT
1430      LN = 0
1440      GO TO 104
1450  501 CONTINUE
1460      STOP
1470      END
```

APPENDIX B
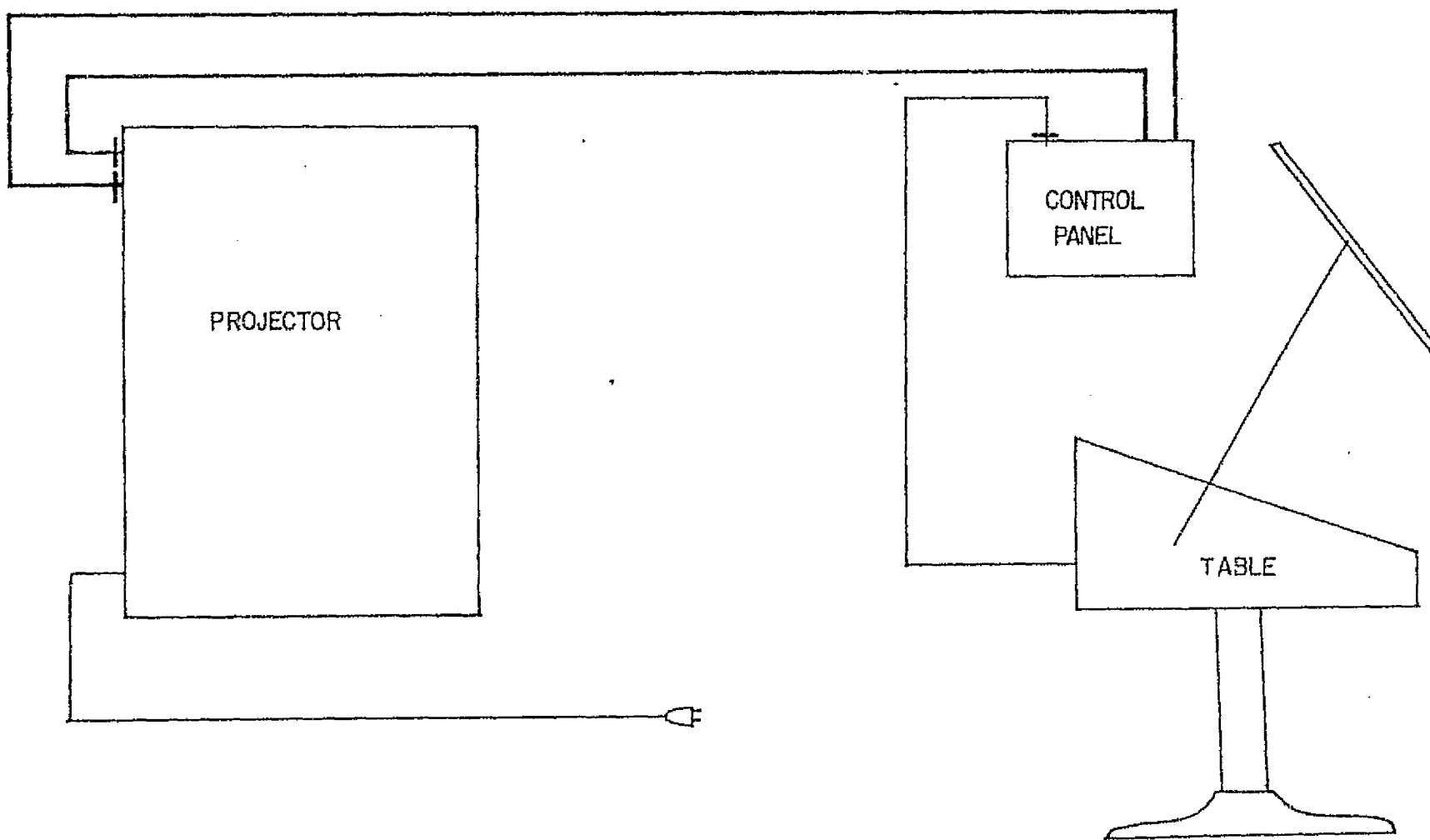
MULTISPECTRAL IMAGE ANALYZER

SYSTEM FEATURES

The system is designed to perform scientific analysis of imagery: in particular from Landsat and Aircraft. It embodies in a single implementation the features found in existing image-analysis equipment, plus additional capabilities. The system is composed of an Image Projection and Control Unit which includes:

1) The Image Former

2) The Image Work Table Unit.

The system operates in two basic modes: a) the *Image Combination Mode*; b) the *Image Compositing Mode*.

In the *Image Combination Mode*, up to four black and white transparencies of the same scene are inserted into the Image Former. The four images are combined optically and projected simultaneously onto the *Work Table* as a single registered image. Various operations can be performed independently on each of the (up to four) images: selective filtering (color), flickering, fade-in-fade-out, light intensity dimming. The scale of the combined image can be magnified up to 100 times, allowing for example the superimposition of satellite imagery onto large-scale aerial photographs, topo maps and similar.

In the *Image Compositing Mode*, the black and white image representing each band is first developed onto a monochromatic image, which reproduces the original to a high fidelity of geometric registration. This can be done in any one of 9 color-hues. It is then possible to operate in two modes:

a) Inserting each monocolor transparency (up to four), repre-
senting a different band, into the *Image Former*, superim-
posing and registering them, and projecting the combina-
tion onto the *Work Table*.

b) Superimposing by simple means (external to the system) two
or more single color images, representing different bands
of the same scene, and constructing therefrom a single
multicolored image. This image can then be inserted in any
one of the four *Image Former* projectors and projected onto
the *Work Table* for analysis.

Method b) allows the user to construct his own color composites,
up to 220mm format, with the advantage that he can vary the density
and color of each image to bring out the most desirable features. The
economic advantage is the very low cost of compositing, which allows
ample leeway for experimentation and optimization. The quality is
fully comparable with EROS-type products.

A special case of working with composite images is the use of al-
ready-prepared color transparencies such as those purchasable from the
EROS Data Center.

The basic advantages of the system are the following:

It can precision-expand the images up to 50:1, and up to 100:1
at lesser precision, thereby allowing superimposition of a wide
range of imagery scales of the same area.

It provides the analyst with a clear and large image on a con-
venient, solid work table, without forcing him to look through
lenses or optical devices, thereby providing the best match
between man and machine.

It provides rapid, smooth, remote and flexible capability for
registering images, changing colors, and applying various pho-
tointerpretation devices, allowing the analyst to use simul-
taneously all the tools available for maximal extraction of in-
formation from imagery.

It combines into a single device the features of the two basic systems currently available on the market, i.e.: 1) the transfer type systems, which project an image onto a flat surface, allowing superimposition; and 2) the color-additive systems, which combine various images of the same scene onto a single image. Existing transfer systems within the same price range do project single images, but do not combine multiple images; existing color-additive systems combine images, but have limited projection capability.

The system provides the added capability of reproducing high quality, density-controlled, precision-registered color images from the original black and white, at very low cost (approximately $0.25 per copy). This capability represents an added degree of freedom in the radiometric domain.

The salient items of comparison between the systems are shown in Table B1.

An important consideration is the size of the image acceptable by the system. Landsat and most aerial images fall prevalently into the sizes of 70mm (54mm information size) and 9" X 9" or 225mm (185mm information size). In the case of Landsat, both sizes contain the same information: except that the Landsat pixel size is approximately 24 microns in the 70mm, 70 micron in the 220mm format. Since the eye's resolution is of order 70 microns, the 70mm imagery must be expanded 5-10X and the 220mm imagery 2-3X to reduce the contribution of the eye to within acceptable limits.

The expansion can be accomplished either by microscopy or by projection. Experience has shown that projection matches far better the human analyzer's physiopsychological preference. This is the first requirement for magnification. The second requirement stems from the

need to match the Landsat scale with commonly available ground truth scales. This is where the high magnification is most important.

Experience has shown that very seldom does one need to work with the entire Landsat frame (35,000 Km^2). The overwhelming majority of applications deal with detailed studies of areas of hundreds, at most a few thousands of Km^2. The use of the entire Landsat frame is mostly limited to selecting the smaller area to be studied. Hence, there exists very little practical need, and significant added cost, to provide the capability to magnify 50 or 100X the large 220mm image. Instead, the Multispectral Analyzer System allows an equivalent capability to the user: namely to copy the 220mm image in essentially perfect rendition, and to cut therefrom the selected 70mm area (representing 3,000 km^2) for projection.

TECHNICAL SPECIFICATIONS

IMAGE PROJECTION AND CONTROL UNIT

- o Handles up to four image transparencies of format 70mm, simultaneously.

- o Each of the four images can be spectrally filtered independently, via insertion of any combination of three quality color filters (Wratten #25 Red, #47 Blue, #8 Yellow, or equivalent) per image. Open gate position also provided. Filter insertion independently and remotely controlled on all four images (maximum of thirty two different color combinations).

- o Registration of all four images, or subsets thereof, by separate, remotely controlled three-degree of freedom adjustments: rotation, up-down (Elevation), right-left (Azimuth).

  Caution: the capability to register the four images onto each other depends upon the precision of manufacture of the original imagery. For example, Landsat four-band imagery of the same scene is generally registered adequately. Landsat images of the same scene taken at different times (multitemporal) are in some cases not exactly registered one with the other. In this latter case, the equipment permits selective registration of any portion of the image under study.

- o Brightness of each of the four images vary independently by means of remotely controlled rheostat type dimmers. The brightness range is continuous from zero to maximum illumination. This permits the maximum separation of color unhampered by contrast/brightness effects.

- o Variable flicker capability remotely controlled with full interruption of light on all four images. Two flicker modes are provided; manual remote and automatic remote. In the automatic mode, the flicker continues automatically until turned

off by the operator: the flicker frequency is variable remotely by the operator. In the manual mode, the operator selects one or more of the images: flicker is provided by depressing a foot pedal. Typical useful flicker frequencies empirically determined are of order 2 cps.

o Independent and remote focus on all four images.

o Overall scale expansion on all four images, ratio up to 1:50 (1:1,000,000 scale imagery can be expanded to 1:20,000) in precision mode, up to 100:1 maximum. The scale range is set manually by translation of the image-forming equipment. The fine adjustment is provided by a remote-controlled, approximately 1:1.5, continuous scale expansion on all four images.

o Manual fade-in fade-out control of the image by means of separate control which varies the illumination ratio between the imagery under study and the superimposed aerial photography or map.

o Capability to photograph the image projected onto the work table. This is provided by means of a sturdy camera mount, easily attachable and detachable.

o A vacuum system under on-off control by the operator can assist in holding the tracing paper or maps firmly onto the work table.

The control panel is of the "remove-and-relocate" type. It is movable to several positions (e.g., on either side, or one left one right of the operator), to best comply with the operator's preferences. Mechanical relocation of the control panel is accomplished by means of pre-arranged brackets and corresponding fasteners: electrical connections are relocated by means of multiple plugs.

o Maximum dimension of image projected on work surface: approximately 60 x 50 centimeters.

o Precision quality color-corrected lens train (Buhl variable
focal length or equivalent) on each projecting system.
Registration accuracy better than 20 microns at image center,
no worse than 40 micron at edges (Referenced to original
image).

o The capability to evaluate image errors and distortions is
provided by means of separately insertable optical reticle
bearing calibration patterns.

o Ruggedized metal construction, Operating ambient temperature:
14°C to 27°C. Storage temperature: -40°C to +50°C. Shock
and Vibration: Laboratory environment. Aero or autotransportable
when packed in box supplied with equipment.

o Power input: 110 volt A.C., 50-60Hz, angle phase approximately
2,000 watts.

o Fuzing: Reseattable power breakers.

o The equipment is designed for easy access for maintenance
and repair without the need of specialized tools.

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   Part 3-B - Cumberland and Tennessee River Basins;

   Part 5 - Hudson Bay and Upper Mississippi River Basins;

Part 6-A - Missouri River Basin above Sioux City, Iowa;

Part 6-B - Missouri River Basin below Sioux City, Iowa;

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